G.E.C. Journal

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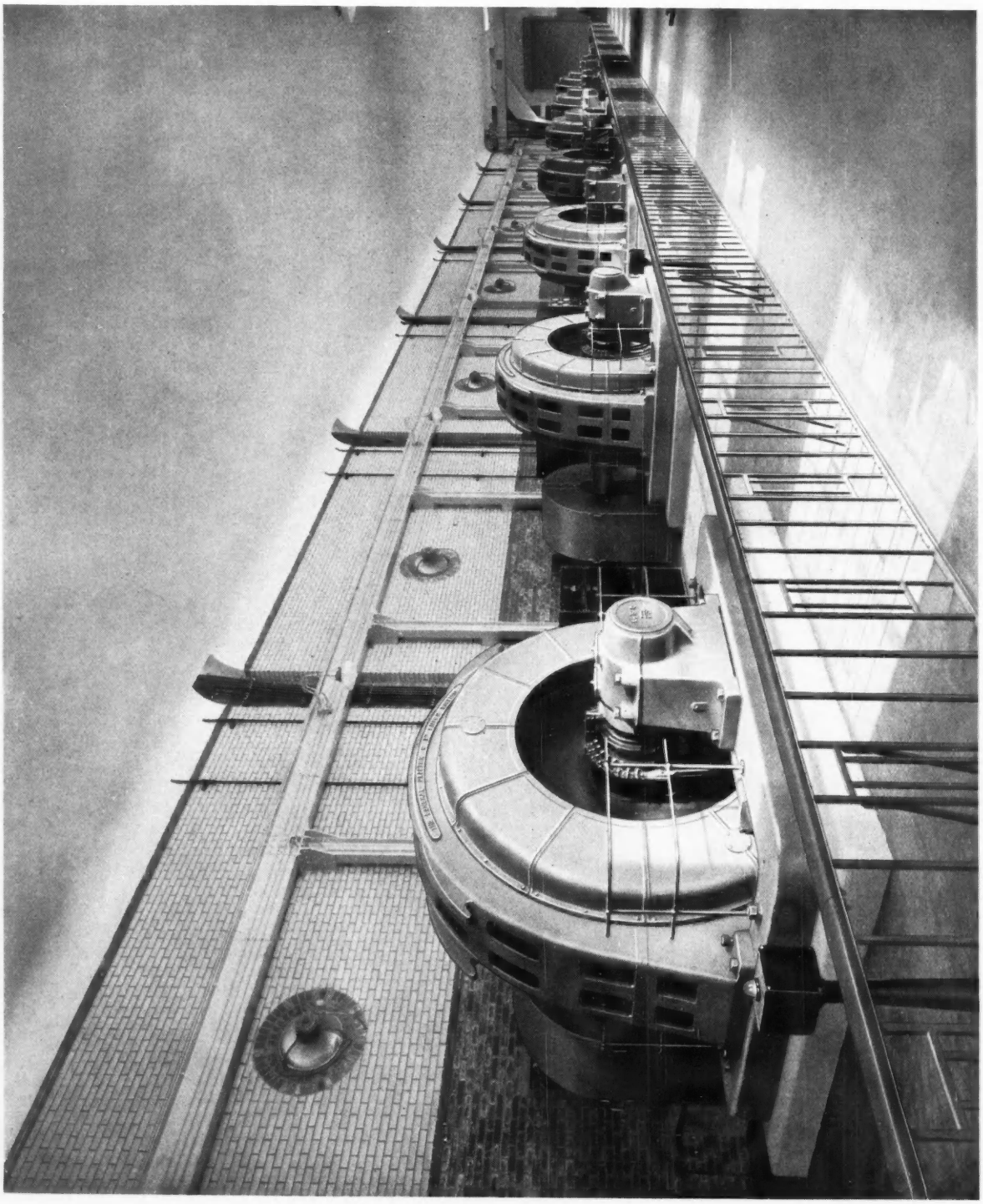


PAPER MILL ELECTRIFICATION.
Seven 2,500 h.p. slipring induction motors, 6,600 volt, 3 phase, 50 cycles, 250 r.p.m., driving process equipment in the Kemsley Paper Mill of Edward Lloyd, Ltd.

G.E.C. Journal

VOL. VII. FEBRUARY, 1936. No. 1.

Electrical Progress and Development During 1935.

By H. W. RICHARDSON, B.Sc. M.I.E.E.
Editor of the "G.E.C. Journal."

ONE of the greatest tasks of the engineer is to simplify. When the first endeavour is made to translate an achievement of experimental science into terms of practical commercial machinery, frequently the efforts of the development engineer and the model builder afford little idea of the form which eventually the equipment will take. The initial aim is to ensure that essential working parts will function with proper efficiency. Suitable assembly and workshop methods of production are subjects for later consideration. But through all the many stages involved, the true engineer strives to improve efficiency, not by increasing the complexity of apparatus, but by making it more simple; "gadgets" are introduced and retained only if indispensable.

The pumpless and air-cooled mercury arc rectifier, which has been introduced by the G.E.C. during 1935, conforms to this engineering ideal, for it represents a much simpler and no less efficient unit of electrical equipment than the earlier types available. This notable achievement in the development of electrical converting plant comes at a most opportune time, for the use of mercury arc rectifiers is continually increasing, and they will be required in much greater numbers as electric railway schemes proceed. Some description of the pumpless rectifier is given later in this article.

The year 1935 will always be famous for the Silver Jubilee celebrations of King George V. and Queen Mary. This great event provided opportunities throughout the Empire for the further development of the art of illumination, and the buildings and spaces floodlighted bore testimony to the high standard attained by modern floodlighting methods. The number of floodlights required to provide for the almost countless number of schemes undertaken exceeded expectations, but the demand was met.

Striking advances have been achieved as the outcome of research work upon cold cathode high tension discharge tubes. The introduction of special powders into the tubes has led to increased efficiencies of an unexpected order, and far reaching results already are evident. This subject is considered further below.

Of the volume of progress made by the Research Laboratories no part makes so wide an appeal as that which concerns television. For that reason in proceeding to discuss the work of the Laboratories this subject is dealt with at the outset.

TELEVISION.

A section of the laboratories has been extended and specially equipped for television development. Two high definition transmitters were installed in the summer of 1935, one principally for radio transmissions, the other for a wire channel. These are operated with a view to the improvement of transmission methods, and are also used for testing complete receivers.

The work on receivers covers the theoretical design of circuits and the evolution of production designs in co-operation with the factory.

CATHODE RAY TUBES FOR TELEVISION.

The development of cathode ray tubes for high definition television reception, has now been in progress for some considerable time. The essential differences between these tubes and the more familiar oscillographic tubes, are :—(1) the method of focussing the beam, (2) the introduction of means for modulating its intensity, and (3) what is perhaps most noticeable, the considerable increase in size of the bulb. With regard to the latter, diameters of 12ins. or greater are now quite common practice, giving a television picture of the order of from 9ins. to 12ins. wide. The design of the bulbs for these tubes to give a practically flat end of such large diameter, is one of the many interesting problems which has had to be solved. With regard to the design of the electrodes for modulating, focussing, and deflecting the electron beam, apparatus for investigating the behaviour of experimental electrode systems has been developed. Maximum brightness and minimum distortion of the picture, with maximum sensitivity of the cathode ray tubes, are the objectives which have to be kept in view.

Testing plant, including life testing apparatus, has been designed and is now operating.

Recent developments have been concerned with preparations for quantity production for television receivers. A model production unit has now been in operation at the Research Laboratories for some time for the purpose of studying manufacturing problems, and recent developments have been concerned with the application of the experience gained to production in the factory.

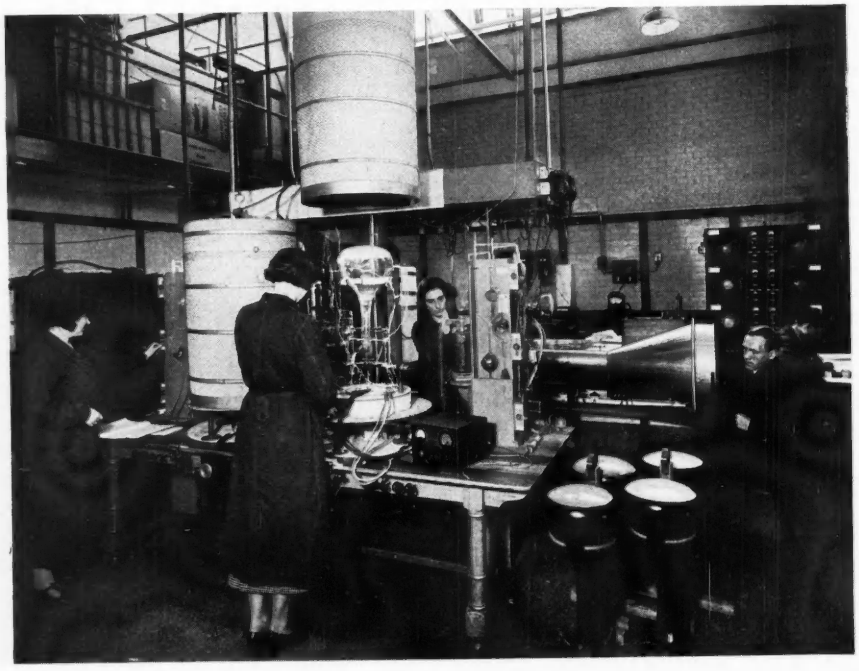


Fig. 1.—Cathode ray tube laboratory at Wembley.

COLD CATHODE TUBES.

The improvements in cold cathode high tension discharge tubes have been chiefly in the direction of efficiency, lumen output and maintenance. These factors are becoming of greater importance than hitherto, in view of the increasing application of these tubes to interior lighting.

In the "Cleora" type of tube the efficiency is increased and new colour effects are obtained by coating the inside of the tubes with luminescent powders. These powders convert into visible light of different colours the quite invisible ultra violet light emitted by the mercury-argon discharge. The colour of the luminescence depends upon the type of powder and its mode of preparation.

Much of the ultra violet light is not transmitted by the glass tubing, and in consequence it proves necessary, particularly in the case of some of the newer specially efficient powders, to place them inside the tubes.

Much work has been directed to the development of the powders. Some of those which have recently been evolved give surprisingly high efficiencies. Ordinary plain mercury blue tubes have a luminous efficiency of about 5 lumens per watt, but when these are internally coated with the new powders the light output, for the same power consumption, may be increased by four to twelve times

according to conditions, including the nature of the powder.

Pink, yellow, green and blue are amongst the colours which can be obtained with the new powders, some of which are approaching the commercial stage.

The efficiency tends to fall off somewhat during life. However, some of the new powders which have been developed luminesce under the action of a discharge in pure neon. Excellent yellow, yellowish white and pinkish tubes have been obtained with these powders. The efficiency, although not so high as with some powders in a tube containing mercury, is nevertheless between one and a half and twice that of filament lamps of the same voltage. Even more important is the fact that the tubes show no appreciable fall in efficiency or lumen output during life.

These tubes, either of one colour or a combination of colours give a very pleasing light suitable for interior illumination, although they are also likely to be of importance for advertising and display signs.

"OSIRA" FLOODLIGHTING TUBES.

Considerable improvements in the efficiencies and luminous outputs of the mercury floodlighting tubes have been described in the G.E.C. Journal.[1] These included an increase from 8.5 lumens per watt to 12 lumens per watt in the pale blue and green tubes, and from 6.0 to 9.0 lumens per watt in the dark green. During the past year, while there is no such large improvement to record, there are a few points which call for mention. The candle power maintenance of the mercury tubes has been improved and the luminous output and efficiency of the dark blue tube have been increased. The total lumens from the dark blue tube are now 1,900 against 1,350, and the overall efficiency has increased from 4.2 to 5.5 lumens per watt. A demand is now arising for floodlighting tubes of lower wattage, and these are now in the course of development.

HETEROCHROMATIC PHOTOMETRY.

The earlier investigations already fully described in this Journal[2] have been continued and many intercomparisons carried out with other laboratories in this country, on the Continent and in America.

As the result of these extended investigations and intercomparisons further progress has now been made in the accuracy to which the unit of light can be determined in terms of the visible radiation from electric discharge lamps and other coloured light sources.

COMMERCIAL PHOTOMETRY OF ELECTRIC DISCHARGE LAMPS.

The fundamental work referred to above has been applied to the establishment of standards of reference for use in the commercial photo-electric photometers designed with special circuit arrangements to enable electric discharge lamps to be measured at commercial speeds. This type of photometer, which has been in service during the past year, was fully described in the last issue of this Journal.

A study of the accuracy obtainable with this type of photometer and intercomparisons with other laboratories has shown that in the case of discharge lamps as well as tungsten filament lamps the accuracy of repetition is higher than that attainable by commercial visual methods. Using electric discharge lamps standardised by the methods developed for this purpose and referred to in the previous section, it is possible to maintain a degree of absolute accuracy satisfactory for commercial requirements.

STREET LIGHTING.

The technique which has developed for the determination of road reflection properties has been employed during the past year for measurements on various road surfaces. Successful attempts have been made to use a portable lamp post for the tests and a camera only two feet from the ground. The application of the results to practical road lighting problems is now being investigated.

THERMAL PROBLEMS IN LIGHTING FITTINGS.

With the increasing use of higher wattages in fittings, and the introduction of the high-pressure mercury discharge lamp, the question of the temperatures attained inside lighting fittings has required close study. The temperatures of lamp-caps, leads and glassware in lighting fittings have been measured and methods have been developed ensuring that the temperatures do not exceed safe values. Particular applications of this work have been to street-lighting lanterns and to interior fittings, both of the decorative and industrial types.

ULTRA-SHORT WAVE VALVES.

The general study of the production of ultra-short wave oscillations has been continued with special reference to the circuit problems arising in the application of these oscillations to radio communication and electro-medicine. A special circuit arrangement for use with magnetron valves has been developed for electro-medical applications to avoid troubles due to the essentially variable nature of the load. The development of air-cooled anode valves for ultra-short waves has proceeded, and outputs of several hundred watts are now possible at 3 metres wavelength. A fundamental study of voltage measurement at very high frequencies has been carried out and measurements are now possible at wavelengths down to about 1 metre.

1. G.E.C. Journal, Vol. IV., No. 4, p. 199.
2 G.E.C. Journal, Vol. V., No. 3, p. 125.

On the receiving side work has been carried out on the reception of wavelengths down to about 20 cm. by means of magnetrons and "acorn" triodes.

RADIO INTERFERENCE.

A specially screened room has been set aside at the Research Laboratories for the investigation of radio interference problems, that is, the effect of electrical appliances on radio reception in their neighbourhood. Quantitative measurements are being carried out on the interference caused by electrical appliances, and these measurements allow of an attack being made, on logical and quantitative lines, on the problems of reducing any interference effects which they might cause. As the next step, units have been designed for the purpose of suppressing these effects.

DESIGN OF LOUDSPEAKERS.

The technique of loudspeaker design and construction has reached a point at which almost any desired performance can be given between the limits set by cabinet size on low note reproduction and interference noise on high notes. Great attention has been paid to achieving the most pleasing result with every type of set when used by listeners in normal surroundings. Special investigations have been directed to details of design, and of the materials used in the moving parts, to increase efficiency and avoid overtone production; at the same time the reliability of the product has been a major consideration.

PHOTOCELLS.

For a long time past persistent efforts have been made by those responsible for the design and manufacture of Osram photo-cells to convince users that such characteristics as stability and frequency are of greater importance than sensitivity, which has hitherto been the user's main criterion. There is some evidence that users are at last beginning to realise that this view is the correct one.

During the last year appreciable progress has been made in improving the emission of the cathode; at the same time greater stability and less variation from cell to cell has been obtained. As a result, cells of normal sensitivity can now be produced having much lower gas magnification. Therefore their quality in respect of all their other characteristics is greatly improved. These cells, termed CWG, have a sensitivity of 100 mA/L, with a gas factor as low as 4.

The new processes are being developed in the works, and it is hoped that a complete range of the new cells will be available in the near future.

HEATING APPLIANCES.

A $7\frac{1}{16}$ inch diameter heavily loaded hotplate has been introduced with features similar to those embodied in the 2,250 watts 8ins. diameter plate which was available for the first time during 1934. The loading of the new hotplate is 1,750 watts, compared with the 1,200 watts which was the rating of the earlier hotplate of this size.

A method of construction for sheathed wire elements has been developed whereby accurate control of the insulation between the coiled heater winding and the sheathing tube can be obtained. Apart from exact centering of the coil within the tube the grade of the insulating material can be controlled at will both in composition and grain size. This enables the best electrical insulating properties to be obtained together with a high thermal conductivity for the refractory insulation. These elements have a wide field of application both for domestic and industrial heating, *e.g.*, immersion heater elements for domestic hot water supplies, immersion elements for kettles, and elements for space heating panels.

A form of low temperature panel heater has been developed. The heater unit embodies sheathed wire elements, and is separate from the visible panel which may be of metal or stone. Normally the average surface temperature of the panel is not intended to exceed 160°F.

METALLURGY.

In radium therapy it is necessary to protect the nursing staff, and also those parts of the patient's body not under treatment, from the radiation. This is usually accomplished by screens of lead, since the absorption of gamma-rays is directly proportional to the density of the metal used. The thickness of the lead necessary, particularly with large radium units renders the apparatus very bulky. A special alloy has therefore been developed in the Research Laboratories for this purpose which is 50 per cent heavier than lead, but at the same time is cheap compared with the only alternatives, gold and platinum. The alloy contains over 90 per cent of tungsten, has a density of 16.5, and although hard can be readily machined. Several hundredweights of the new alloy have already been used in the construction of radium "bombs," and the reduction in size enables the treatment to be applied much more effectively.

MERCURY ARC RECTIFIERS.

Reference has already been made to the introduction of the pumpless and air-cooled mercury arc rectifier. A considerable amount of experimental work was involved, and the success achieved is sufficiently indicated by the fact that there is already available a six-anode pumpless air-cooled steel tank rectifier with full load capacity of 450 amperes at pressures up to 800 volts direct

current. Three of these units (fig. 3) are being installed by the London Passenger Transport Board.

The new equipment possesses many obvious advantages. So far as smaller sizes are concerned it should prove an altogether better proposition than large glass bulb rectifiers for outputs of, say, 300 amperes and upwards. Its metal construction renders it more robust than a glass bulb, and it can withstand heavier overloads and more severe short circuits without damage. In comparison with earlier steel tank equipments of larger size a much smaller amount of floor space is required. In particular, when several units can be grouped together important economies may be effected. In situations where cooling water difficulties may arise the value of the new development is very apparent.

A factor which has contributed in no small measure to the success of the new rectifier is the G.E.C. patented vitric seal[3]. An early model of the rectifier has been in intermittent operation for a considerable time without any deterioration in the vacuum as indicated by the Pirani gauge fitted to it.

Improvements are continually being effected in the design of previously existing types of mercury arc rectifier equipments, and the standard range includes units with capacities from 1,000 to 5,000 amperes. Rectifiers of larger output can be built if required. It is of great interest that industrial organizations are now installing mercury arc rectifiers, while it also has to be recorded that a rectifier recently installed in one of the Copenhagen municipal sub-stations was the first manufactured by a British firm for service on the continent of Europe.

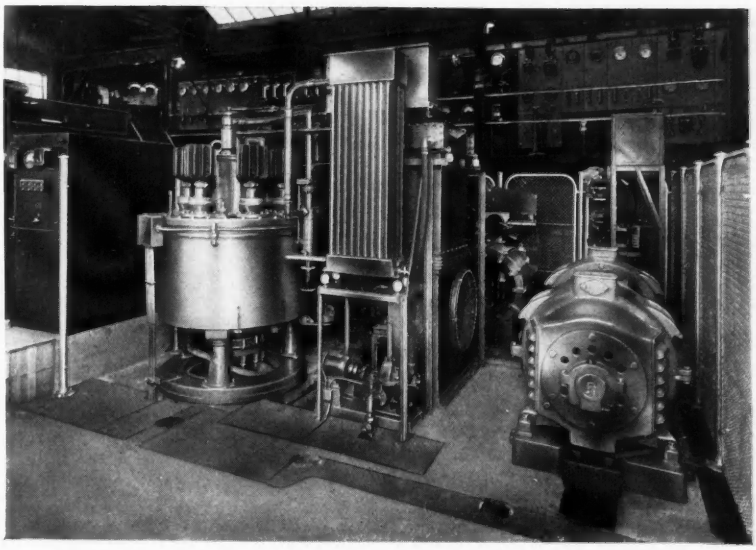


Fig. 2.—1,000 kW, 6,600 volt, 3 phase, 50 cycles to 460/560 D.C. mercury arc rectifier equipment at Farm Gate sub-station, Poplar.

Fig. 3.—Two of the three 6-anode air-cooled pumpless mercury arc rectifiers, 400 amps, 600 volts D.C. for the London Passenger Transport Board.

In view of the fact that a normal type of automatic voltage regulator is not applicable to mercury arc rectifiers, a new regulator has been designed for use with grid controlled rectifiers. It depends for action on the variation in the speed of a small motor consequent on changes in applied potential difference. In addition to this voltage-responsive motor, a motor running at a standard speed is used, and an electrical differential gear, employing rotating torque machines, and interposed between the two motors, makes the necessary correction of the voltage by shifting the brushes of the synchronous distributor supplying the control grids. This regulator is simple and rapid, and the relatively large forces needed are obtained without sacrifice of accuracy. Various special load-voltage characteristics are easily obtained by the use of series windings on one of the motors.

This regulator can be used for the new pumpless and air-cooled rectifier.

3. Patent No. 215475/1923.

GENERATING PLANT.

The design of generating plant has undergone no fundamental change, but machines of the usual types have been built for many classes of service, covering a range of outputs from 50 kVA to 62,500 kVA. It is of significance that generators have been built for export to every part of the world, the numbers sent to India and South Africa in particular indicating the great headway which electrification is making in these territories.

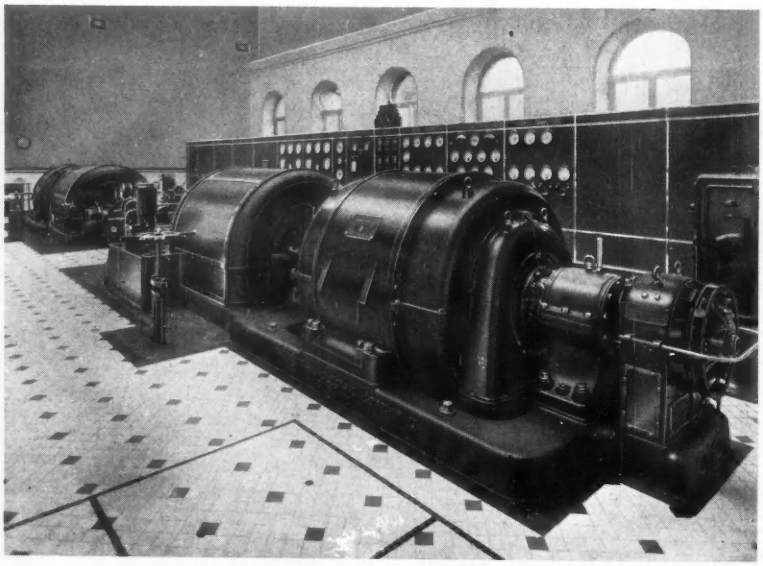


Fig. 4.—Power station at the Manningham Mills, Bradford, of Listers & Co., Ltd., showing two G.E.C.-Fraser & Chalmers turbo-alternators and main switchboard.

Fig. 5.—Portable A.C. welding set.

ELECTRIC WELDING EQUIPMENT.

The increasing use of electrodes having a generous flux coating has brought about a general recognition of the advantages offered by the welding transformer as a cheap and efficient means of providing power for metallic-arc welding. When suitably covered rods are used, it has been proved that welding performed with alternating current can be as reliable as that employing direct current.

In order to meet the demand for static welding plant a range of transformers has been standardised for single and multi-operator work (fig. 5), covering a current range of from 30 to 350 amperes. Current control is obtained by means of tappings from carefully proportioned choke coils located in the same oil filled tanks as the transformers, which are made portable where required by the provision of suitable wheels.

A new type of direct-current, motor-generator set (fig. 6), has been developed for single operator work. This unit houses the stators of the motor and generator within a single steel shell, and the rotors are mounted on one shaft between ball bearings. A waterproof casing encloses machines and control gear, and rubber-tyred wheels render the set portable. Although this set is capable of a range of outputs of from 50 to 300 amperes, the weight of the complete unit is under 1,000 lbs., and it is capable of being moved easily by one man.

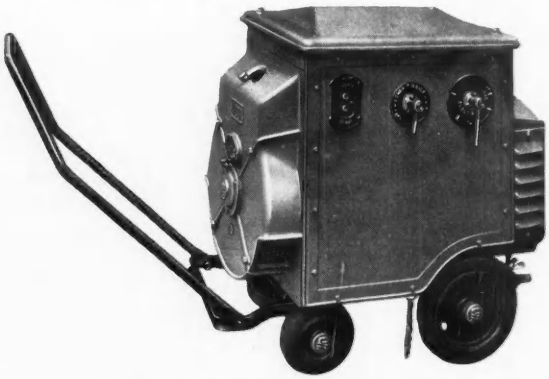


Fig. 6.—Portable D.C. welding set.

For large welding installations compound-wound motor-generator sets are available having a voltage range of from 45 to 60 volts according to the class of work undertaken. The use of such a low voltage has obvious advantages, providing (1) increased efficiency, (2) a short arc under all conditions, and (3) freedom from shock. In order to obtain perfect arc stability at this voltage a

reactance unit has been developed for use in each welding circuit in conjunction with portable current regulating rheostats.

MOTORS AND INDUSTRIAL SCHEMES.

The various forms of totally enclosed motors which have been introduced during the last two or three years have been widely used in industry. These machines include frame cooled, cowl cooled and diaphragm cooled types of motor. An interesting design of frame cooled machine was recently manufactured, a fabricated structure being employed. By adopting welded construction greatly improved ventilation was obtained. A machine of this type in an intermediate stage of manufacture, is shown at fig. 7. The cores of the machine are built on a jig, and the fabricated housing which forms an air cooler is assembled on the jig and welded in position. This construction makes it possible to use a large number of steel tubes through which external cooling air passes. The internal cooling air circulates past these tubes so that an effective cooling system is obtained without the internal cooling air coming into direct contact with the external cooling air at any point. A much larger cooling area is obtained than is possible with a cast iron frame, and further, increased strength is combined with less weight.

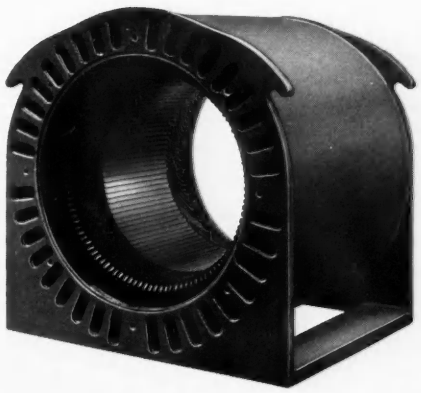


Fig. 7.—Fabricated stator of frame cooled A.C. motor.

The attempt to improve efficiency in the textile trade by increasing the spinning speeds has created a demand for a 3-phase commutator motor with automatic speed control. A motor of this type has therefore been designed, the speed of which is regulated automatically from the spinning frame so as to adapt the speed to the requirements of the spinning operation. A system of cams and gear wheels, which can be set according to the particular yarn to be spun, changes automatically the brush position of this motor.

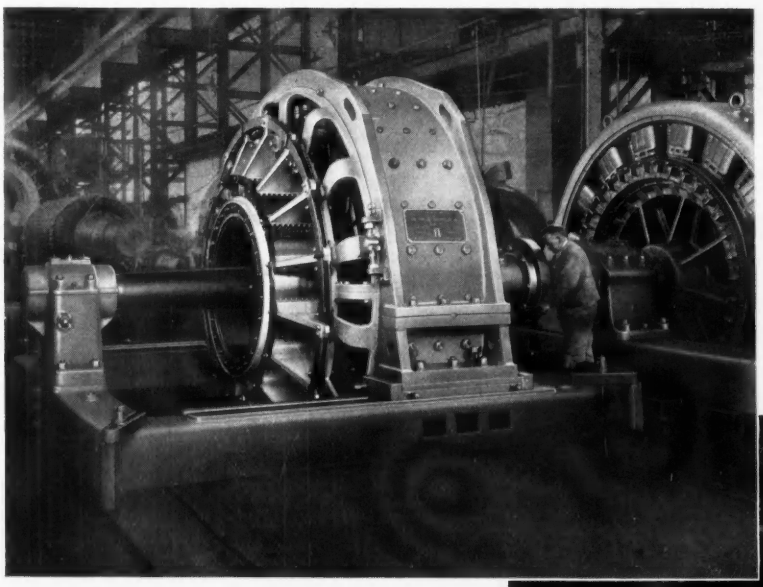


Fig. 8.—2,400 h.p., 550 volt, 160r.p.m. winding motor for Roodeport Mines, South Africa.

Motors and control gear for winding equipments continue to be manufactured for many mines and collieries, some of the largest motors being for South African gold mines. One of these together with the Ward-Leonard set which controls it are shown at figs. 8 and 9.

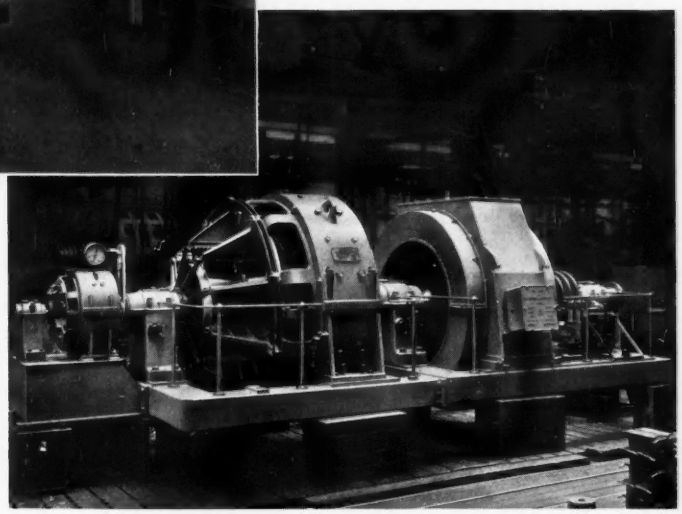


Fig. 9.—1,900 kW Ward-Leonard motor-generator set for operating the winder motor shown in fig. 8.

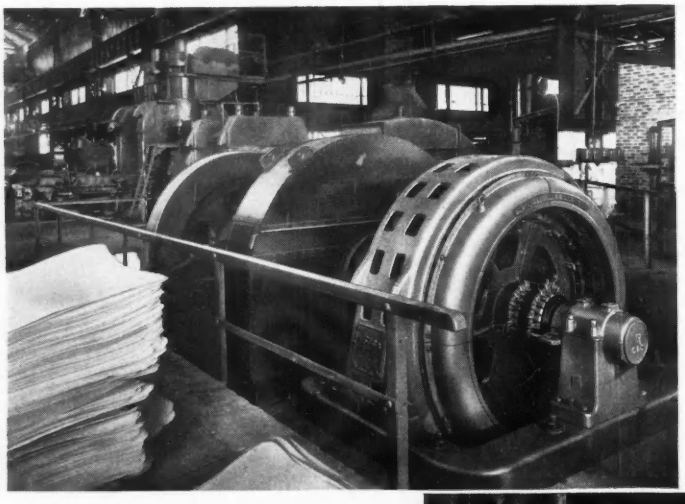


Fig. 10.—Part of a comprehensive rolling mill installation at the mills of Australian Iron & Steel Co., Ltd., New South Wales. View shows 1,500 h.p., 6,600 volt, 295 r.p.m. motor driving sheet mill.

In another South African mine a winding equipment has to be installed at a depth of 7,000 feet. In order to reduce the noise as far as possible, the high speed induction motor of the Ward-Leonard motor-generator set has been designed with a purely axial type of ventilation, the heat being extracted from the cores by a large number of tubular vent ducts through which the ventilating air passes. This allows a relatively low air speed in the machine and avoids noise due to the whirling of air in the confined space of radial ducts through the teeth and in the air gap of the machine.

Equipment for the mines of the International Nickel Company of Canada, Ltd., includes three 1,200 h.p. direct current motors. One of these drives a cage hoist, while the other two are coupled in tandem to form a 2,400 h.p. unit for driving a rock hoist. For both winders Ward-Leonard motor generators are employed, the motors of these sets being synchronous machines. In the case of the rock hoist the synchronous motor drives two generators, one for each of the winding motors.

Further schemes for the re-organization of the iron and steel industry have been reflected in the demand for large electric rolling mill equipments. For both The British (Guest, Keen, Baldwins) Iron & Steel Co., Ltd., and Dorman Long & Co., Ltd., electric motors for roughing and finishing mills are in course of erection. Two electric rolling mill equipments completed during the year should be mentioned, the first for Arthur Lee & Sons, of Sheffield, which was fully described in the last issue of the G.E.C. Journal, and the other for the Pirelli-General Cable Works at Eastleigh.

There has been great activity in new and extended industrial electrification schemes, and large numbers of motors with appropriate motor control gear have been installed in undertakings; industries which should be mentioned especially in this connection include gold mines, paper mills, brickworks, and sugar plantations.

HIGH POWER SWITCHGEAR.

The completion of the High Power Testing Laboratory at Witton is of the greatest importance in view of the need for a complete investigation of the performance of modern high power switchgear and reactor units under heavy short circuits. This whole subject is being considered in a series of articles in this Journal, of which the first appears on a later page.

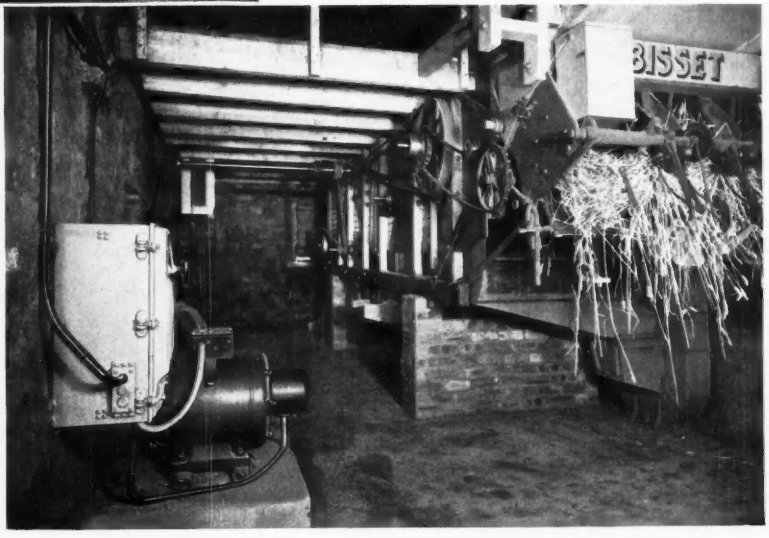


Fig. 11—25 h.p. slipring motor driving threshing machine on a Scottish farm where extensive use is made of electricity.

One of the improvements in the design of 33,000 volt metalclad switchgear relates to the use of bakelised paper condenser bushings for busbar insulation in place of bitumen or oil insulation. By this means the orthodox bulky compound filled busbar chambers are entirely eliminated, thus very considerably reducing the weight of the unit. This new form of insulation provides a very high degree of safety. Side blast arc control pots are now incoroprated in this class of switchgear.

Progress in the smaller types of metalclad switchgear has been achieved by the incorporation of features which simplify maintenance.

The range of outdoor oil circuit breakers has been increased by the addition of two sizes; both are designed for a maximum breaking capacity of 1,000,000 kVA, one for 66,000 volt circuits and the other for 110,000 volt circuits. These breakers are fitted with side blast arc control pots.

It is convenient to record here that a 75,000 kVA 11,000 volt outdoor type oil circuit breaker with busbar chambers has been introduced. This gear offers all the well-known advantages of unit type switchgear, and it is very suitable for ring main service.

AUTOMATIC CONTROL APPARATUS.

Few fields of electrical engineering can show more rapid progress than that devoted to the automatic control of plant and equipment. New methods are constantly being devised. Brief details of certain interesting schemes just completed or in course of progress will indicate the general trend in this subject.

Complete automatic control gear is required for the Kincardine swing span bridge now being erected over the Firth of Forth. The scheme provided is fully automatic, and the motion of a single controller handle causes the bridge to go through the whole operating sequence, which consists of changing of traffic lights, sounding a warning bell and siren, lowering gates, withdrawal of locking bolts and wedges, moving of the swing span, and the "open" signal for the resumption of river traffic.

The indication of the swing span's position created a difficult problem which is satisfactorily solved in the following way. A large indicator dial, "Selsyn" driven from one of the swing span motors and graduated in feet of travel, will enable the actual motion of the span to be followed by the bridge operator, while to aid in lining up the span in the "road open" position a photo-electric indicating device is provided. A "target" on the abutment may also be lined up with a vertical rod on the moving span, and finally, a sequence switch (closed only when the road way is accurately placed) positively prevents operation of the locking bolts and wedges at other times. The locking bolts and wedges are actuated hydraulically and a synchronising gear has been developed to keep them exactly in step during shooting or withdrawal so as not to subject the swing span to any undue strains. This gear is able to compensate for slight leakage in the hydraulic system of any bolt or wedge while discriminating between slight and serious leakage or complete pump failure; in the latter case the withdrawal of all wedges is stopped and a hand pump must be used to complete the motion.

A second control scheme of most comprehensive character was required in connection with a complete coal handling plant for the Lunghai Railway, China, which

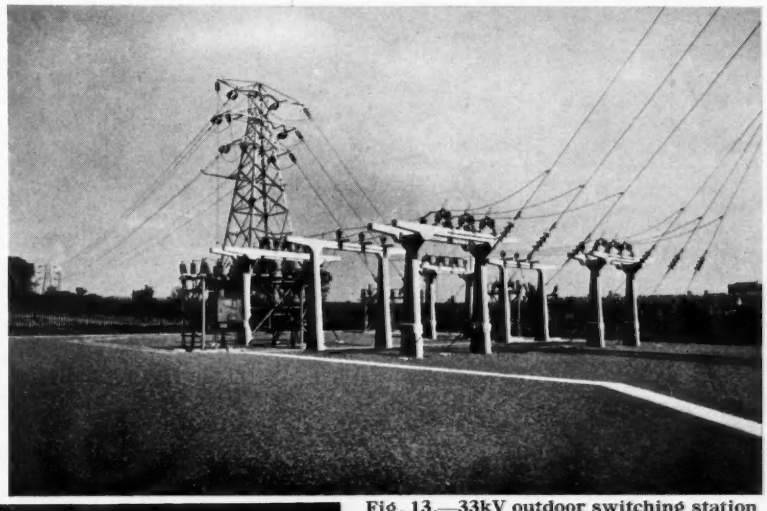


Fig. 13.—33kV outdoor switching station at Rothwell Road, Kettering, showing on the extreme left of the equipment one of the two new outdoor type oil circuit breakers designed for a breaking capacity of 350,000 kVA at 33kV.

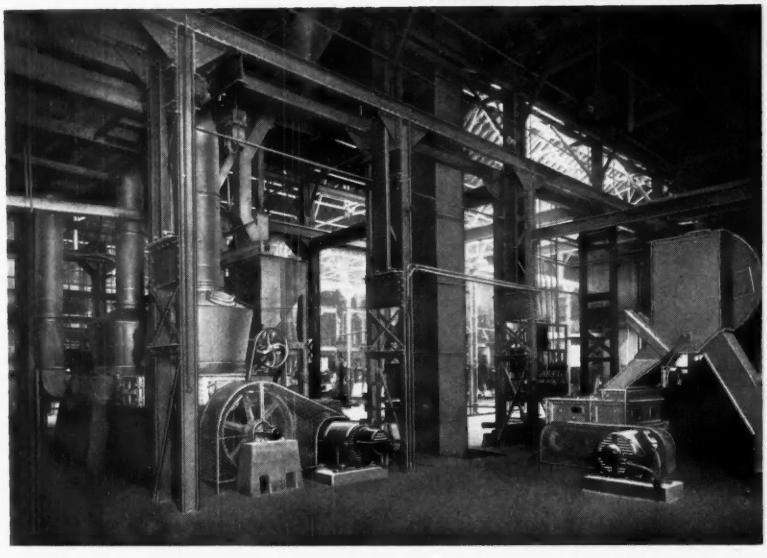


Fig. 12.—Typical of many factory electrification schemes completed during the year—the works of The British Plaster Board Co. of Erith, Kent, showing two of the motor drives.

has been supplied and erected by Fraser and Chalmers Engineering Works. One of the principal items of the equipment is a 40-ton car dumper which feeds the conveyor system.

This system is sequence interlocked to allow coal to be carried either to a dump or to a loading tower

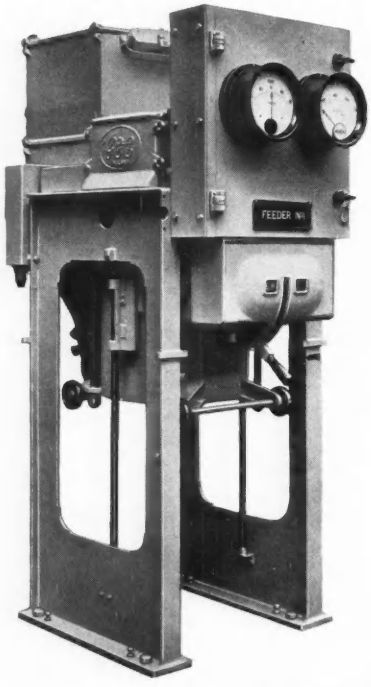


Fig. 14.—150,000 kVA, 11,000 volt metalclad switchgear unit.

from which it may be discharged into ships. The car dumper is fully automatic with push button control, and an interesting feature is the automatic slow running period during which the fulcrum point of the car dumping frame is changed. Ward Leonard methods are employed, and the simplicity of the control is illustrated by the fact that use is made of the natural time constant of the machines for acceleration and retardation.

Two super calender drives for the paper mills of Albert E. Reed & Co., Ltd., are operated completely by booster control. The motor for each of the drives is controlled by a variable voltage booster in series with the D.C. line. The booster voltage in turn is controlled by a motor operated field regulator. A starting sequence is designed to deal with the conditions peculiar to super calender drive, which involve a starting torque of 3 to 4 times full load immediately followed by creeping speed. The following is the sequence: on starting, about full load torque is applied and at the same instant a timing relay is started. If the calender moves the voltage is such as to give a creeping speed, but if the calender fails to start the torque is raised after a short interval to $2\frac{1}{2}$ times full load (or more if needed); if the calender starts at this torque the voltage is automatically reduced to creeping speed value, while failure to start causes complete shut down.

Electrical equipment for the testing of automobile engines has reached a high state of efficiency. Particular attention has been given to the meter equipment. The horsepower meter has been made to register actual horsepower at any speed, being automatically compensated for variable friction and windage losses. A control pillar in connection with automobile engine sets, designed to the special requirements of the Austin Motor Co., Ltd., is shown at fig. 15.

For the new municipal sewage scheme at Southampton seven electric motors are required, two of 190 h.p., two of 90 h.p. and three of 34 h.p. capacity. All these machines are float operated. Control equipment provides for that combination of pumps to be run which is most suitable for prevailing conditions. Each float switch circuit is brought to a plug board

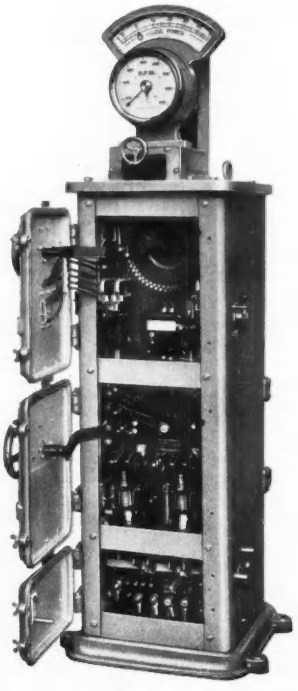


Fig. 15.—Automatic contactor equipment for testing automobile engines.

where the right plant may be selected. As it is undesirable to run pumps of widely differing capacities in parallel close together, the connections are so arranged that a rise in sump level starts successively the 34 h.p., 90 h.p. and 190 h.p. pumps, each shutting down its smaller predecessor.

PROTECTIVE GEAR.

Protective gear for large radio valves fitted with

three phase filaments has been developed. It is important that if for any reason a break occurs in one or two phases of the filament, the current should be cut off altogether. This is ensured by means of a separate small current relay associated with each phase. The contacts of these relays are so interconnected that when all the relays are up or all down, there is no tripping circuit; but if one is different from the rest the tripping circuit is at once completed. This scheme is also serviceable for the protection of certain types of feeder, either in association with some other protective scheme or by itself.

An important development of the well known McColl protective system is the introduction of an induction type relay (fig. 16) which will eventually replace the older beam type relays. The salient advantages of the new type include the following:—(a) Lower volt-ampere consumption of the coils, (b) Definite time relay (adjustable) before the trip contacts are operated, (c) The relay is more compact and of neater appearance, and (d) ready means is provided for adjusting, time delay, bias and minimum setting.

In this relay the moving system is an induction disc instead of a beam and the movement of the disc is controlled by means of two coils, the restraining and operating coils. Under normal conditions the restraining coil drives the movement to hold the moving contact against the off stop, while the sufficient energisation of the operating coil during fault conditions rotates the disc in the opposite direction to close the contacts. The inclusion of a definite minimum time delay feature is a particularly valuable feature for transformer protection, as it is unnecessary to short circuit the relay operating coils during switching. Voltage surges tend to cause faulty tripping of differentially protected transformers and this also is prevented by the time delay feature. This relay is particularly valuable for cases where movement or vibration of the support are to be expected, such as on board ship.

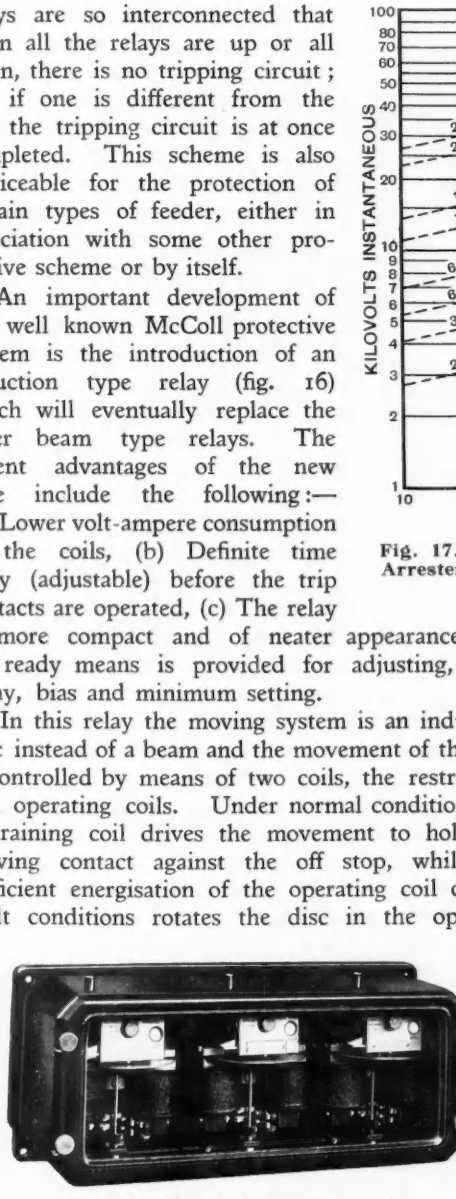


Fig. 16.—New induction type relay.

The new type of multicontact intertripping relay shows advances as compared with earlier types. The contact drum carries six sets of contacts which can be made normally open or normally closed in any combination. The advantages offered are (a) lower operating current, (b) improved form of latch, and (c) a stouter and neater case.

A simpler and less expensive type of intertripping relay has also been developed which can be used where a maximum of two changeover contacts are sufficient. Both types of relay are fitted with heavy silver contacts which are capable of making 25 amps, 110 volts D.C. and breaking a load of 5 amps, 110 volts D.C. (non-inductive).

The range of "Quenchol" fuses has been extended, both as regards current and voltage ratings. A range of high power cartridge fuses for voltages up to 660 is also being developed in sizes up to 200 amperes and with breaking capacity of 25,000 kVA. The fuses are tubular in form, with short and compact bodies made of "Steatite," and they can be fitted in standard ironclad switchgear or made up into distribution boards. A positive indicator is fitted on each holder, which indicates when the fuse has operated by charring the label; a noiseless explosive paste has been developed for the purpose.

There has been considerable demand for multi-gap type lightning arresters, particularly from overseas, and the range has been extended to be suitable for circuits up to 22,000 volts with insulated or solidly earthed neutrals. The volt-ampere characteristic curves of these arresters is given in fig. 17. This type of arrester has a true safety valve action.

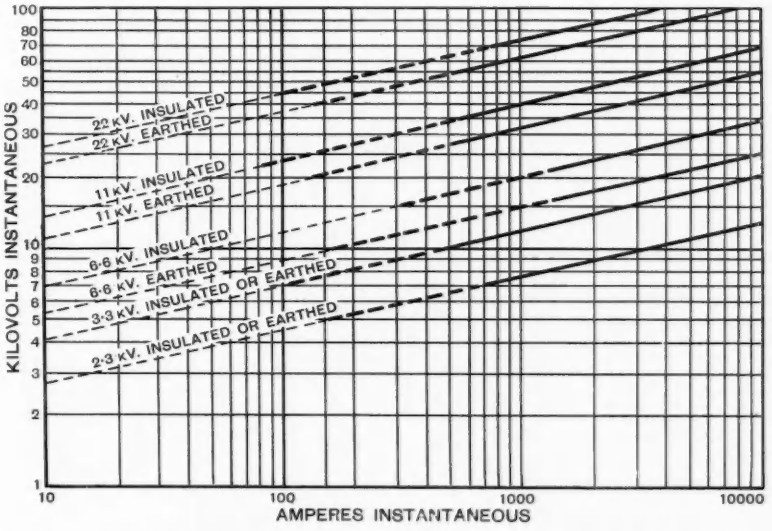


Fig. 17.—Volt-ampere characteristics of multi-gap lightning arresters. Arresters discharge at beginning of thick plain portion of curve and cut off at beginning of thick dotted portion.

OPERATION COUNTER.

A device is often required which will register the number of times some operation has occurred. There is no difficulty in designing such an instrument when the amount of power available is large; but occasionally the counting is required of some such phenomenon as the passage of a discharge which may amount to only a very small and transient current. A counting mechanism has been devised for this purpose in which the motive power is supplied by means of a clock spring, and the discharge is only called upon to function as a trigger device which releases the escapement. So sensitive is this mechanism that it is operated with reliability by the discharge from a 20 micro-farad condenser charged to a potential of only 50 volts. The whole apparatus is compact and simple.

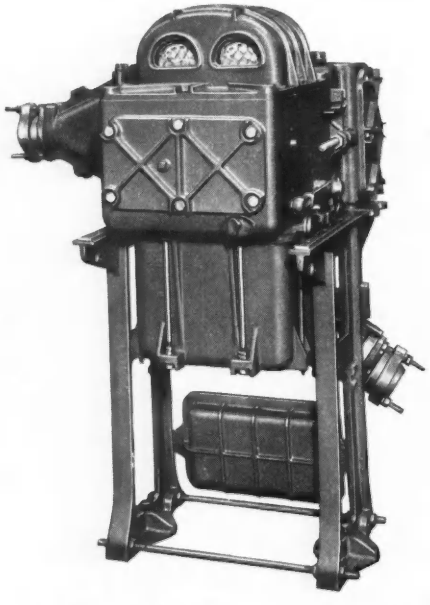


Fig. 18.—Flameproof oil-immersed circuit breaker.

FLAMEPROOF SWITCHGEAR.

A flameproof drawout oil circuit breaker, fig. 18, for 440 volt and 3,300 volt circuits supplements the range of existing models of this type. The maximum breaking capacity of the breakers is 25,000 kVA. They have received the approval of the Mines Dept.

A range of "Flit" type flameproof cable boxes has been developed, and these units also have been approved by the Mines Dept. They are available in sizes for both 3,300 volt and 6,600 volt circuits in straight and right angled forms. All the usual arrangements of cable boxes required in collieries and mines are catered for, *e.g.* both sizes of box can be supplied in straight or right angle form and suitable junction chambers are available for tee-off circuits.

Portable mining sub-stations for use at the coal face are now being produced, a typical example being shown in fig. 19.

VOLTAGE REGULATION.

A new high voltage transformer on-load tap changing switch has been put into production. It is suitable for any voltage from 22 kV up to 132 kV. Its range covers transformers up to 45,000 kVA, but owing to its simple unit design, it is an easy matter to extend the current range. Voltage regulation was the subject of a recent article in this Journal[4]; further reference here is therefore unnecessary.

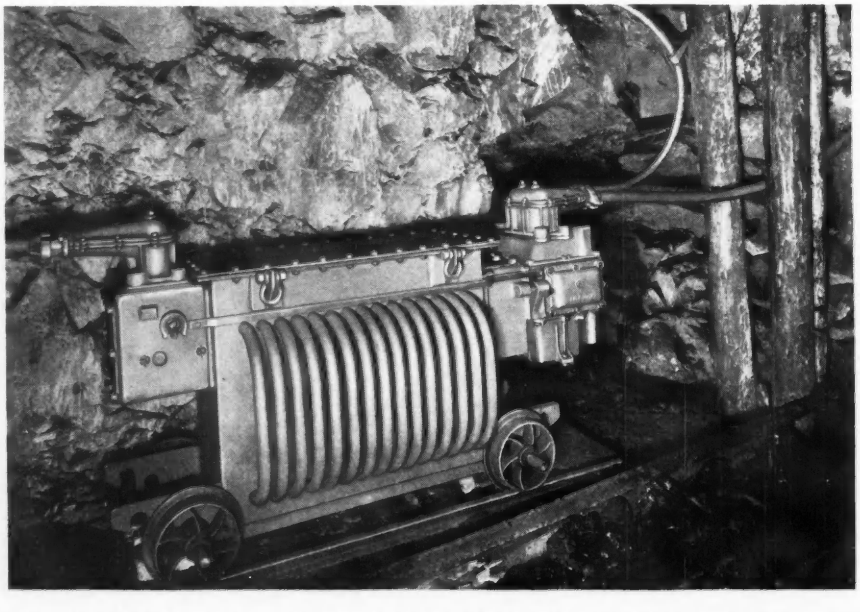


Fig. 19.—75 kVA portable mining sub-station fitted with 3,300/440 volt transformer.

REACTORS.

Owing to the general increase of system kVA throughout the supply industry, in many cases it has been found necessary to install feeder reactors to limit the power passing through existing switches if and when a short circuit should occur on the line. A feeder reactor of the standard oil immersed iron shrouded design, for use on a 6,600 volt, 3 phase, 50 cycle circuit, normal current 437 amps per phase, short circuit

4. G.E.C. Journal, Vol. VI, No. 3, p. 138.

current 8,740 amps per phase, *i.e.*, 100,000 kVA, has been tested up to its full short circuit rating in the high power testing laboratory. The reactor, after the full test, was examined and found to be in perfect condition, there being no movement of coils, laminae or superstructure. This reactor conformed entirely to the standard design which has been supplied during the last three years.

ELECTRIC TRACTION.

During the year increased activity has been noticeable amongst the various transport undertakings throughout the country, many of which are undertaking the replacement of their existing stock as well as extensions to their systems. Several new schemes have been investigated, amongst which one of particular interest is an entirely new type of equipment which is being built for experimental work on the London Passenger Transport Board section of the tube railways.

The introduction of trolley buses on a large scale is being undertaken by the London Passenger Transport Board. This represents the first stage in the replacement of tramcars by trolley buses in London. During the year the G.E.C. began delivery of 101 trolley bus equipments for this scheme. Each equipment comprises an 80 h.p. motor, compound wound for regenerative control, together with the control gear. The latter is arranged for regeneration and rheostatic braking. A battery of unusually large capacity is installed in each bus, and is capable of providing sufficient power in emergency to propel the bus for a short distance without overhead wires.

For Nottingham Corporation, 30 trolley buses have been completed and are in service. These buses are of the field controlled series motor type, each being equipped with an 80 h.p. motor and remote control gear.

Some interesting developments have also taken place in connection with the electrical equipment of tramcars. A type of tramcar with a single driving end has been evolved by the Rotherham Corporation Transport Dept. These tramcars operate between Rotherham and Sheffield, and at each terminus a looped track enables the tramcars to make each journey with the driving position at the front. In appearance the new tramcars resemble a bus, and since their introduction some months ago they have proved to be highly satisfactory in performance. The electrical equipment consists of a standard tramcar motor operated by high capacity cam-operated direct controllers in conjunction with

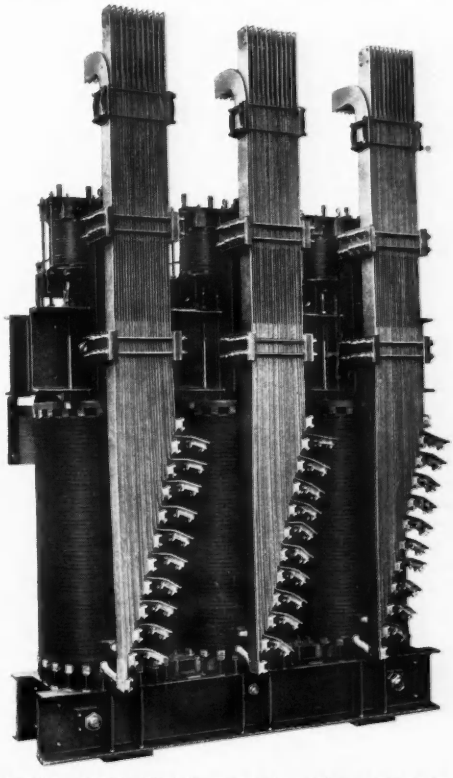


Fig. 20.—3,600 kVA furnace transformer core and windings.

automatic field weakening equipment for maintaining acceleration.

A remote control tramcar equipment is being supplied to Liverpool Corporation. During recent years the performance required from a tramcar has necessitated increased motor capacity. It has con-

Fig. 21.—Leyland-G.E.C. trolley bus in service at Hobart, Tasmania. Body built by Hobart Municipal Tramways.

sequently become somewhat difficult to control these larger motors with direct operated controllers. While cam operated controllers have met this

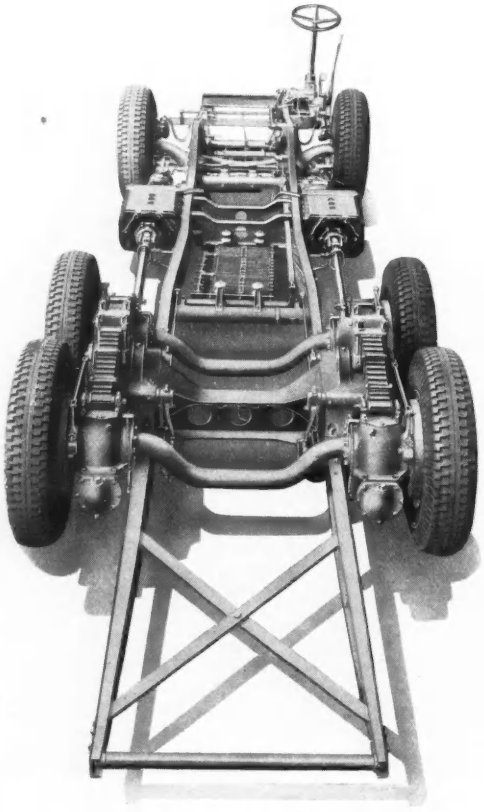


Fig. 22.—Chassis of Leyland-G.E.C. low floor trolley bus showing arrangement of motor drives.

difficulty to a large extent, it has been felt that better results would be maintained, as regards maintenance and reliability, were the recognised railway practice of remote control adopted. In the case of the equipment for Liverpool the control gear is operated by electro-pneumatic means, the motors being specially designed for this heavy duty service.

MARINE ELECTRIFICATION.

The past year has been notable for the greater amount of equipment supplied to shipbuilders for installation on new vessels under construction. The work completed has included plant and accessories in connection with some 15 new ships constructed for various owners, all for trade within the Empire.

Seven recent ships have been equipped with plural starter gear, each equipment controlling 17 motors. The use of this system has enabled the engine room dimensions to be kept down to a minimum, thus providing greater space for cargo. Large individual starters which are virtually inactive during most of the trip but occupy valuable engine room space are replaced by small control units mounted direct on the motors, the remaining gear being on a central switchboard in the switchboard gallery. At the same time a stand-by starter is readily available for every motor. The repeated adoption of this plural starter system in many recent motor ships is clear proof of its reliability and economic advantages.

An interesting equipment for the electrical propulsion of a Diesel-electric tug is in course of construction. The tug will operate on the Thames for the owners, the Erith and Dartford Lighterage Co., Ltd. The propelling equipment comprises a 350 s.h.p. propeller motor supplied with power from a 290 kW Diesel-driven generator, together with the propulsion control gear.

As regards accessories and fittings for marine installation, there has been a greatly increased use of Roanoid moulded fittings for all classes of cabins, bathrooms and alley ways. The chief advantage of these fittings is their non-corrosive properties, and the ease with which they can be cleaned. Their durability has been responsible for their installation even in the crew's quarters of smaller types of cargo vessels just as much as in first class passenger vessels.

Special designs of lighting fittings have been produced in large quantities for new vessels such as the "Strathmore" and the "Orion," while a contract has recently been obtained for the fittings in the public rooms and spaces of the "Queen Mary."

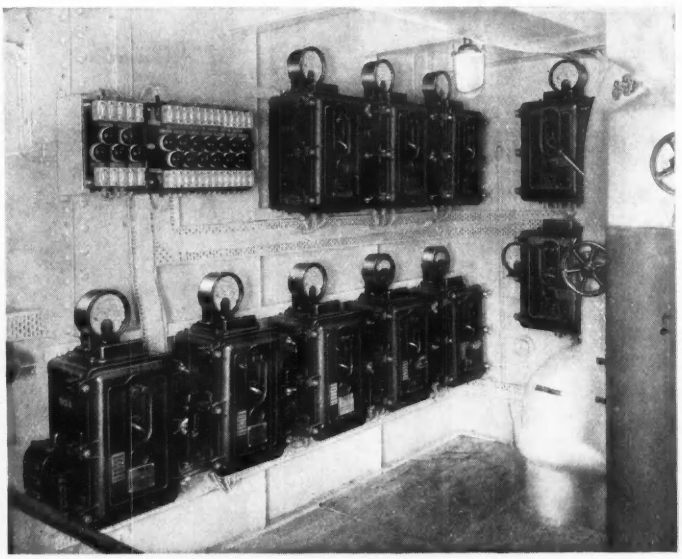


Fig. 23.—Automatic timing-starters for refrigerator and fan motors installed in S.S. "New Zealand Star."

Considerable progress has also been made during the year in the design of electric galley equipment for ships, and twelve such equipments have recently been installed, the most notable of which is that for the "Strathmore." The whole of the electrical galley and pantry equipment on this vessel was supplied, and includes a wide range of cooking and water heating equipment, with a total connected load of 500 kW for the main galley, baker's shop, crew's galley, pantries, and the like.

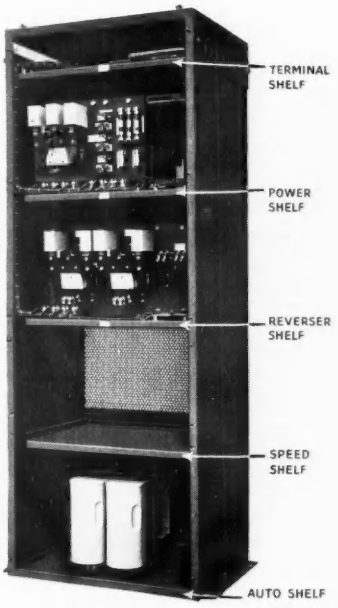


Fig. 24.—Standard single speed dual voltage controller.

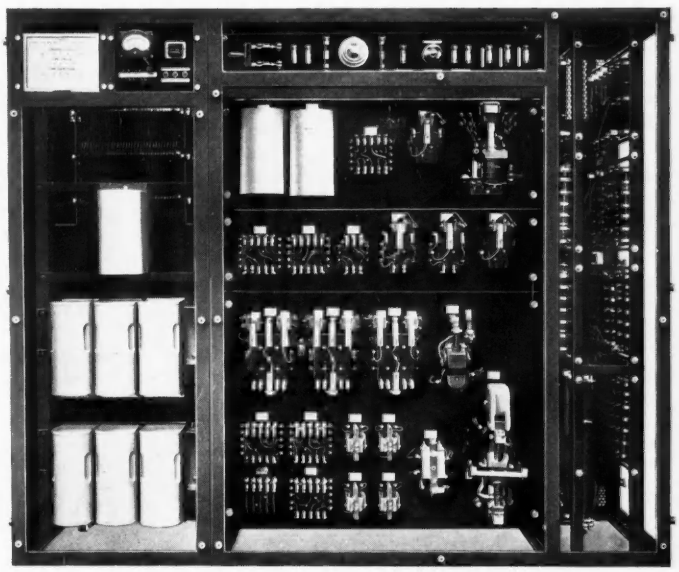


Fig. 25.—Variable voltage Ward-Leonard dual voltage controller.

ELECTRIC LIFT CONTROL.

Dual voltage control is now used exclusively for all types of lift installation on alternating current supply, including single speed equipments, and equipments incorporating 2 speed, 3 phase, pole changing motors, and 2 speed, single phase, capacitor type motors. It is also used for the variable voltage control of D.C. machines. A standard single speed dual voltage controller is shown at fig. 24, and other panels in figs. 25 and 26.

The basic principle of the system rests upon the use of two distinct working voltages. Line voltage is carried only by the contacts of the main contactors feeding the driving motor. The brake coil operates on an independent circuit rectified from line voltage. All other circuits, including the coils of the circuit breaker, main reversing contactors and gate relay, operate on a much lower voltage. For this purpose the line voltage is transformed down and rectified to 50 volts continuous current for use in energising the coils of contactors and relays.

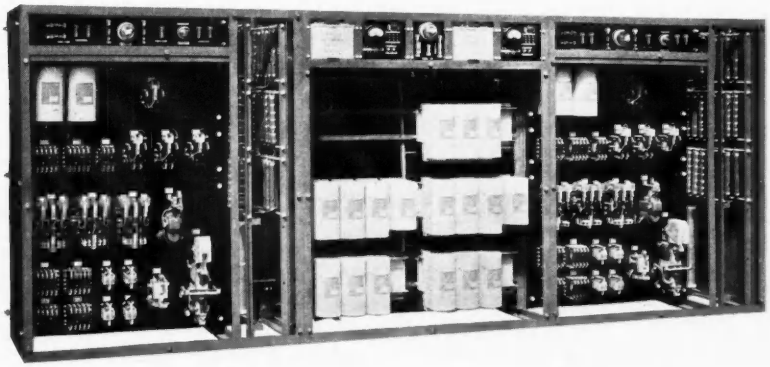


Fig. 26.—Controller for two interconnected, two-button collector variable voltage lifts.

A particularly interesting development of dual voltage control which forms the subject of patents is its application to the variable voltage control of slipring motors. For many years there has existed no satisfactory control equipments for single speed type lifts on A.C. circuits, covering the range between lifts with speeds up to 120 feet per minute and those with speeds up to 600 feet per minute which employ Ward-Leonard methods. Systems which have achieved a limited measure of success in respect of speeds not exceeding 200 feet per minute include pole changing motors, variable speed commutator motors, and also the use of two motors, a slipring machine for starting and for running at full speed, and a slow speed squirrel cage machine to enable a good landing performance to be obtained. Most of these machines,

Fig. 27.—¾ h.p. motor driving motor boat propeller unit.

however, have involved the installation of clutch devices and mechanically operated switchgear.

The patented variable voltage control for slipring motors referred to gives an eminently satisfactory performance, with the result that lifts can now be operated on an alternating current supply at speeds up to 300 feet per minute without sacrifice of accuracy in floor levelling.

A normal slipring motor is employed, and it is accelerated by reducing to zero the value of an external rotor resistance. A speed range of approximately 12:1 is obtained by applying a retarding torque and inserting an external resistance in the rotor circuit of the driving motor. This retarding torque is varied to suit the load in the car, and when a heavy load is being lifted, the retarding force requires to be less than when a heavy load is being lowered, so that by varying the retarding force to suit various loads in the car, it is possible to obtain a constant creeping speed from the motor, irrespective of the load in the car, and since this speed is approximately 18 to 25 feet per minute accurate floor levelling may be obtained. The retarding force is applied by an eddy current brake, and is varied by varying the excitation of the eddy current brake.

Modern flats and multi-storey garages have caused a new control system to be evolved. In these buildings inter-floor traffic is non-existent. In the case of flats all up traffic originates at the ground floor level and requires to travel to various floors, whereas the down traffic originates at various floors and requires to travel to a common floor, that is the ground floor. In garages there are rush hours when the majority of cars are driven up the ramp to the parking floor, and the drivers will travel back to the ground floor by lift, or alternatively travel up the lift and return by driving the car down the ramp.

It will be seen that in these instances it is undesirable for the lift to stop at every floor where a call exists whilst travelling up, since all intending passengers desire to travel to the same floor, that is the ground. To meet these conditions it is necessary for the lift to operate as a normal full automatic push button lift whilst travelling in the upward direction and as a collector lift whilst travelling in the downward direction, *i.e.*, as a one way collector lift.

ELECTRIC FANS AND SMALL MOTORS.

New designs of the "Everest" and "Kingsway" Junior ceiling fans have been produced giving improved performance. Ball bearings are used in place of the plain bearings with automatic lubrication which previously were used. Modifications have been made in the terminal arrangement whereby, instead of exposed terminals, totally enclosed terminals are fitted which are fully protected from dirt and insects. These fans are now capable of running for very much longer periods than heretofore without attention, and thus economies in maintenance costs are effected.

Further additions have been made to the range of skeleton type motors suitable for building into apparatus of various types. Several sizes of stator and rotor are available suitable for building into machine tools using the shaft and bearings which form a part of the tool.

TURBINE PLANT.

The G.E.C. Research Laboratories are engaged in special research with a view to the improvement of turbine efficiencies. For this purpose a wind tunnel (fig. 28) has been erected at Fraser & Chalmers Engineering Works, and the two-dimensional flow through model turbine blades is being studied. The results of this investigation will be applied to a turbine running under controlled conditions. The

work is analagous to research on aeroplane wing sections and propellers.

The ordinary arrangement of steam valves admitting steam to a turbine comprises an emergency valve and one or more regulating valves; the emergency valve is always in the "open" position when the turbine is in operation. Should any of the regulating valves fail to close when load is reduced, the emergency valve is tripped by the overspeed governor. This valve should shut off the steam supply to the turbine, but it may have been in the "open" position for a considerable time and there is no definite evidence that it can be absolutely relied upon to function. Further, if it works properly it is obvious that the turbine will come out of operation. This arrangement of the valves clearly is disadvantageous, involving considerable risk, in addition to disturbance of the power system. Fraser & Chalmers Engineering Works have accordingly developed and patented a new system of turbine governing in order to eliminate so serious a drawback.

This system of governing consists of an emergency valve and one or more regulating valves. All these valves, including the emergency valve, are under the control of the speed governor and of the overspeed governor. The emergency valve opens simultaneously with the first regulating valve, its opening being gradual due to the control of the speed governor; actually its opening is for all practical purposes like that of the regulating valve, the only difference in its operation being that, while it begins to open simultaneously with the first regulating valve, it reaches its full lift preferably at a load slightly below the load obtainable with the first regulating valve in full open position. As a steam turbine in an ordinary power station often carries a load below this particular point, it is clear that the emergency valve will move frequently under the control of the speed governor and will not remain in one position for any considerable length of time; thereby the reliability of its operation is substantially improved, and moreover it can be observed or tested at will. Should any regulating valve fail to operate properly and so cease to control the steam supply to the turbine, the emergency valve, being under the control of the speed governor all the time, will exert complete control of the steam supply, with the result that the overspeed governor will not trip out in such a case, and the turbine will remain in operation until convenient arrangements can be made for the load to be transferred. Briefly, while in the ordinary turbine governing the steam supply is regulated on its passage from the steam main to the blading system only by one valve under the control of the speed governor, in the new patented governing system there are two valves in series under the control of the speed governor; thus the safety of the machine is greatly increased and continuity of power supply is ensured. The emergency governor in this system closes the emergency valve and the regulating valves when normal speed is exceeded by a certain percentage, but such overspeed could only be reached in the case of failure of the speed governor itself or of both the emergency valve and a regulating valve failing simultaneously; these contingencies are most unlikely.

The system possesses further advantages. At no load and very low loads with high steam pressures there may be quite considerable steam leakages through the regulating valves; such leakages may cause the speed control at no load or very low loads to be uncertain, paralleling may be difficult and there is increased risk of the turbine running away when load is suddenly thrown off. In the new system of governing the steam is controlled up to a certain load by two valves in series. At no load the emergency valve and the following regulating valves are practically closed; the emergency valve reduces the steam pressure very substantially so that the leakage through the regulating valves is correspondingly reduced, and the turbine remains under satisfactory control of the speed governor under any conditions of unloading.

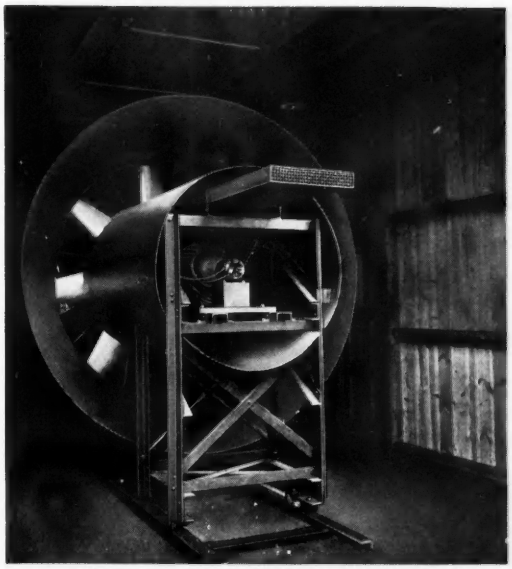


Fig. 28.—Wind tunnel installed in the research laboratory of Fraser and Chalmers Engineering Works, for the study of two-dimensional flow through model turbine blades.

It will be appreciated that, although the emergency valve produces a certain throttling effect at lower loads, it does not produce any additional throttle loss; it only shares with the first regulating valve the total throttling effect which is unavoidable and necessary for such lower loads.

Another important advance aims at the elimination of fire risk due to the ignition of leaking oil

when it comes in contact with hot parts of the plant. To guard against this trouble an enveloping pipe which normally contains no oil is arranged round the oil pipe. If leakage occurs in the oil pipes it is caught by the enveloping pipe which leads it back to the oil tank. The fire risk is therefore eliminated, and at the same time there is no loss of oil in the circulating system.

than those generally used in this country. The wagons vary in size from 44 feet in length with 40 ton capacity of coal, down to 14 feet in length with a 10 ton capacity; the height also varies from 10 feet high to 6 feet 3 inches. In the case of small wagons two wagons can be tipped at once.

To handle these continental wagons the bolster which supports the side of the wagons whilst in the

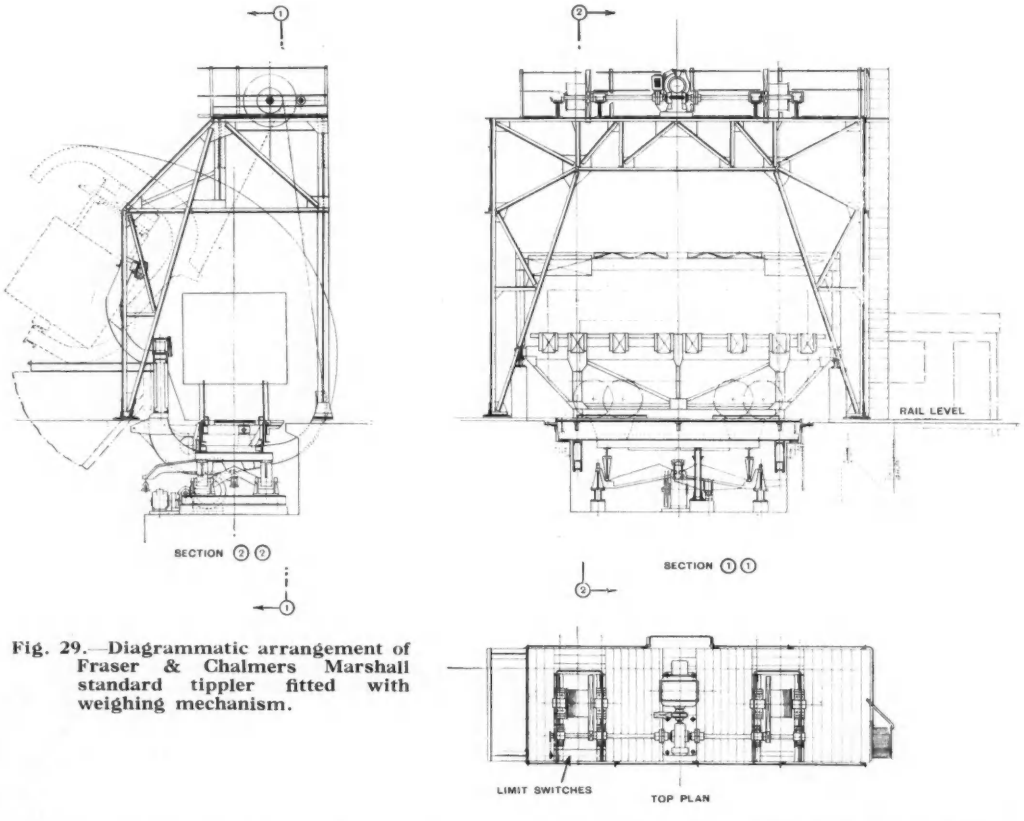


Fig. 29.—Diagrammatic arrangement of Fraser & Chalmers Marshall standard tippler fitted with weighing mechanism.

A new design of impeller for peripheral speeds of 800 ft. per sec. has been introduced in turbo blowers and compressors. This design maintains the characteristic feature of backward bent impeller blades which give the highest possible efficiency. The increased peripheral speed results in considerable simplification of these machines, and at the same time the turbines driving them can be made more efficient without increasing their cost.

MATERIALS HANDLING PLANT.

Reference has already been made to the coal handling plant installed for the Lunghai Railway Company in China. One interesting item of the equipment is a 60 ton side discharge tippler capable of handling 800 tons of run of mine coal per hour. This machine is provided with special features which enable it to handle wagons of continental manufacture, which are of more frail construction tipping positions is arranged with a large flat area built up of wood blocks, placed zig-zag like bricks in a brick wall. Each block is backed by steel springs to give a resilient support to the wagon, and allows local deflection to prevent an excessive force being taken on the wagon projections, such as door handles or projecting stiffening members.

The tippler is arranged with a double point of rotation in order to give as small a drop as possible to the coal in discharging. The electric speed control of the movements of this tippler was described earlier.

A combined weighing and tipping tippler for handling standard wagons of capacities ranging from 12 to 20 tons. It is covered by patent rights[4].

It is practically a standard Fraser & Chalmers tippler, fitted with a weighing mechanism embodying Marshall relief gear for transmitting the loads to the

4. Patent No. 293145

weighing levers and recording mechanism, and is arranged to record automatically the gross and tare weight of each wagon in one location of the wagon on the tippler.

The chief feature of this system is the elimination of shock to the weighing machine. Shock is eliminated under all conditions for the following reasons, (1) through traffic passes on the tippler platform beams, which rest direct on the foundation, relieving the weighing mechanism and hoisting ropes of all stress and strain ; (2) wagons are raised from and returned to the tippler beams without shock to the weighing mechanism, an action which is only possible when this mechanism is independent of the beams ; and (3) the wagon and its load are raised to the weighing position by a slow moving cam lifting device without shock to the weighing levers or knife edges.

The weighing apparatus consists of four lugs fitted to the weigh table beams, and these lugs engage with the threads of the wagon wheels on one side of the wagon and with flanges of the wheels on the other side. Normally the lugs lie below the level of the tippler beam tracks. A cam lifting device raises the weigh levers to the weigh level of the weighing mechanism, and at the same time raises the lugs to lift the wagon clear of the tippler beams ; the weight is then recorded on the weigh machine. After the weight has been recorded, the cam device lowers the wagon on to the tippler beam.

The action of weighing and tipping is arranged to be semi-automatic. This means that if it is required to weigh the wagon only, then the "weigh" button only need be pushed, but if the load is to be tipped as well as weighed, then the tipping button must be pushed immediately afterwards, the empty wagon being weighed automatically on its return. If, however, it is required to tip a wagon only, the "tip" push button is put into operation. On being tipped, the wagon stops at the final tipped position, and the "down" button has to be pushed to start the return journey. This arrangement enables the operator to see that the wagon has fully discharged its contents before lowering. The cam lifting device is operated by a $3\frac{1}{2}$ h.p. electric motor, and its control is of the contactor type, arranged on the same panel as the control of the main tippler motor.

Many very interesting applications of Webb conveyors have been undertaken, of which the following examples are typical. In a cement works a conveyor of this type was installed with bottom opening buckets to carry mixed loads of bulk material from dumps to furnaces. The conveyor is linked up with belt conveyors and weigh hoppers, and is fully automatic in action, it is continuous in operation and effects steady and definite furnace charging without manual intervention. In addition the complete circuit is electrically interlocked, thus ensuring that the relevant quantity of each component is delivered to the furnaces with regularity. The loads total 600 lbs. per charge, each charge being delivered in one bucket. There are 28 such buckets in the circuit, all arranged for selective discharge.

A patented design has been developed for pickling conveyors which enables users to pre-select the time for mixed articles to be immersed in the acid bath. In most present-day practice it is usual to alter the speed of the conveyor passing through the acid tanks so as to vary the time of immersion of the articles loaded on the conveyor. This means that at a given speed of the conveyor the articles would all receive the same length of time of immersion.

In the Fraser & Chalmers design of conveyor the buckets normally pass over the acid tank. But any bucket may be preselected by a setting device at the loading point, and dipped into the acid bath at any preselected points along the length of the bath by a cam and lever motion. Thus the time of immersion of any bucket may be varied. This method offers the further advantage that the tank can be divided into separate sections and the strength or kind of the bath solution may be varied to suit circumstances.

Progress has been made on conveyor equipment suitable for handling food-stuffs, and in addition to

Fig. 30.—Webb conveyor equipment installed in the Longbridge Works of the Austin Motor Co., Ltd.

large savings in labour the question of damage in transit is almost entirely eliminated. The latter benefit has shown up to a large extent in the handling of bananas, which arrive as complete stalks and in a green state. Bruising in that state leads to wasted fruit after ripening, since a bruise on one or two bananas may spoil a whole "hand," therefore the transport of these articles without damage is of great importance. It is possible with a Webb conveyor installation to reduce the manual handling to a minimum.

Fig. 31.—"Osira" laboratory lamp.

FINE COAL WASHING.

In order to meet the growing demand for a fine coal washing plant of reasonable cost, capable of cleaning the finer fractions of coal now produced in increasing quantities due to machine mining and other causes, a plant has been designed to clean $\frac{1}{16}$ inch × 0 coal. A test and demonstration plant has been erected at Fraser & Chalmers Engineering Works.

The equipment installed consists of a fine coal washbox with a rated capacity of 5 tons per hour of $\frac{1}{16}$ inch × 0 coal, together with the necessary de-watering arrangements for the clean coal. The washbox is fitted with a feed inlet tray provided with vertical riffle fins for distributing the raw coal evenly across the width of the box. The bottom of the box is inclined downwards from the feed inlet towards the lower outlet and overflow weir. Wash water spray pipes are placed transversely across the bottom of the washbox and are arranged to give an even distribution of upward flow of water over the whole box.

The principle on which the cleaning process is based is that of hydraulic stratification combined with gravity separation. By this method the raw material subjected to the action of the agitation water introduced from the transverse spray pipes is stratified, so that the heavier material gravitates to the bottom of the box, and the lighter particles or clean coal float in the dense liquid produced by maintaining the coal in suspension in the water, and are carried out of the box by water overflow.

The lower outlet of the washbox is connected to a rotary refuse ejector driven through gearing, and the speed of ejection of refuse is automatically adjusted to the rate of raw coal fed to the wash box. For this purpose a flap is fitted to the raw coal feed launder which operates the speed regulator of the D.C. motor driving the refuse ejector. In this manner a bed of refuse of suitable depth is maintained in the bottom of the washbox. Included in the refuse ejector drive is also a variable speed gear, the adjustment of which determines the proportion of raw feed to be discarded.

The refuse falls into the water seal box connected

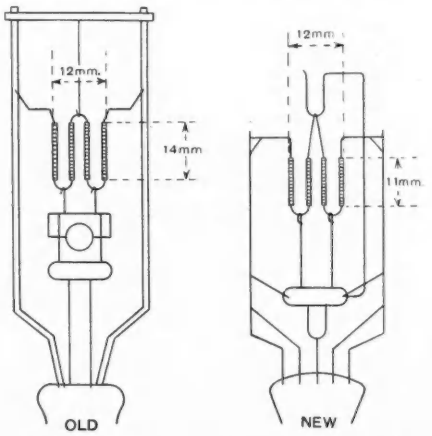


Fig. 32.—Comparison of old and new method of mounting projector lamp filament.

to the lower end of the inclined refuse scraper type drainage conveyor, and is discharged into a pen where weighing and sampling may be carried out.

The clean coal from the washbox is laundered on to a de-watering screen, where water and a certain proportion of slimes are extracted and taken to a thickener cone. The overflow of clarified water from this thickener is returned to circulation in the washer system, while the thickened sludge from the bottom of this cone is pumped back to the middle of the de-watering screen. The clean product passing over this screen is discharged by a chute to a pen for weighing and sampling.

The demonstration plant referred to has been erected adjacent to an existing commercial scale Chance plant, first, in order to facilitate the feed of correctly sized raw coal to the fine coal washer, and

secondly to show its capabilities when working in conjunction with the Chance washer. These two units together provide an efficient and flexible combination for washing any complete range of commercial sized coal.

ELECTRIC DISCHARGE LAMPS.

The efficiencies and lumen maintenance of the standard high pressure mercury lamps continue to improve. The values obtained at present are as follows :—

Rated Lamp Watts.	Initial Lumens per Watt.	Average Lumens per watt up to 1500 hours.	Lumens per watt at 1500 hours.
250	36	31	29
400	45	37	34
400 (Colour modified)	37	29	27

Other wattage ratings both lower and higher are under development.

By the use of specially designed magnetic deflectors, referred to later, the lamps may now be burnt in a horizontal position.

A special form of electric discharge lamp known as the "Osira" laboratory lamp (fig. 31) has been designed to meet the demand for a light source giving a line spectrum which can be used as a source of known wavelengths for calibration purposes, or from which a single line can be isolated for work requiring monochromatic radiation. These lamps are made to give the pure characteristic arc spectra of the following elements, sodium, cadmium, mercury, cadmium and mercury combined and zinc. The lamp consists of a small inner tube (the light source) mounted in an outer jacket attached to an ordinary four-pin radio valve cap. The inner tube contains the metal which is vapourised, and whose spectrum is excited by the passage of an electric discharge between electrodes at the ends. A small quantity of inert gas is also included to facilitate the initial discharge. The outer jacket is evacuated to maintain the inner tube at a constant high operating temperature.

TUNGSTEN FILAMENT LAMPS.

Rather more than a year ago it was decided to standardise the coiled coil filament for use in high voltage lamps for general lighting service, and it is of interest to review the large amount of work involved in developing the mass production of such lamps.

Although England was among the pioneers in the development of coiled coil lamps, little experience of their use in daily service had been gained up to a year ago, due to the fact that the number of them which had been in service was relatively small, *i.e.*, in comparison with the total production of incandescent lamps. Therefore it was not without some misgivings that technicians faced the problem of machine manufacture of coiled coil lamps on a scale large enough to supply the needs of lamps for general service. It is true that laboratory tests had shown over and over again that coiled coil lamps could be designed to give from 10—20 per cent more light than single coil lamps for equal life and wattage consumption, and it is true also that service tests in industrial conditions had shown that the processes available were adequate to give lamps of high quality; but those responsible for production and quality were faced with a very big task in achieving, under the conditions of mass production, that very high degree of uniformity which is required in the modern lamp.

The primary problem is the production of a wire which, after the violent treatment of coiling on an exceedingly small mandrel, followed by a second coiling on a larger radius, can be fixed —or "stabilised"—by the simplest possible form of treatment in the intricate coiled form which it must retain throughout the life of the lamp. Perfectly satisfactory stabilising processes have been known and used by the G.E.C. for many years; but the great

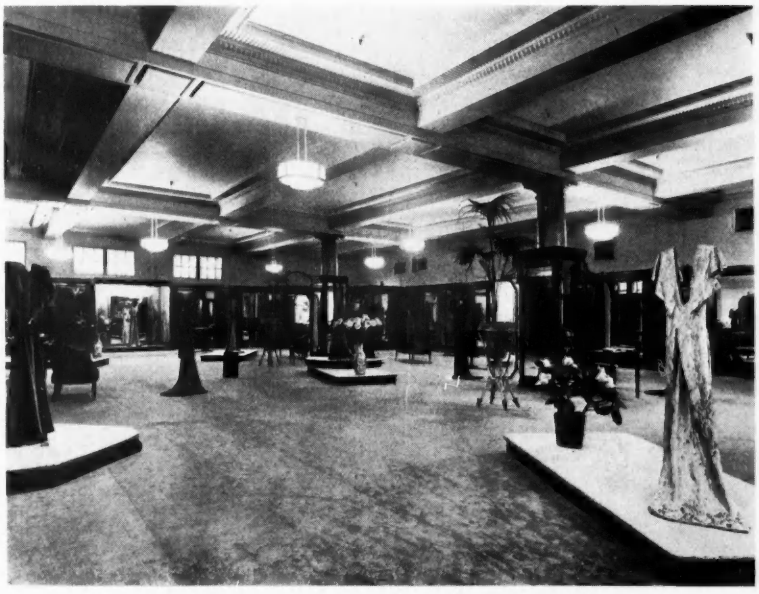


Fig. 33.—Gowns salon of Dickens & Jones, Ltd., of London, showing special lighting fittings.

Fig. 34.—Entrance hall of Lusam Buildings, Johannesburg, one of the large blocks of flats which have recently been erected in this city. The hall is illuminated by specially designed fittings made of blue, green and pink glass rods.

needs (as always) in the mass production of lamps, are for simplification of the necessary processes to the highest possible degree, and for uniformity of one batch of the wire with another so as to reduce as far as possible the number of re-adjustments to be made from time to time in the factory.

Hardly less important, in order to maintain the very high uniformity which has been attained during the last few years in the manufacture of single coil lamps, was the need for improved coiling machines. Owing to the reduced spacing between the primary turns caused by the secondary coiling, pitch accuracy—always important—became even more vital, and for this reason it was necessary to design and make machines capable of producing coiled coils with the highest degree of pitch accuracy. In addition, since there are nearly three times the number of turns in a coiled coil filament as compared with a single coil of similar rating, it was necessary to provide new capacity to this extent, and finally there had to be provided for secondary coiling new machines which would coil the primary helix into definite numbers of turns of secondary coil, leaving short lengths of primary helix uncoiled to mark the cutting points between individual filaments.

Machines to perform the delicate operation of mounting the filament on the supports and lead wires attached to the glass foot of the lamp had also to be designed and built, and the design of such machines involved the solution of a whole series of very intricate mechanical problems.

A very interesting new feature of the coiled coil lamp is the method of avoiding the possibility of flashing on failure. Owing to the concentrated form of filament, the space between the lead wires is comparatively small, and should the filament fail on circuit, an arc is easily struck across the broken ends of the filament, in which case the current taken by the lamp will increase to such an extent that generally the local fuse will come into operation, a source of annoyance to the user which would have made the coiled coil lamp unpopular if a remedy had not been forthcoming. This problem is effectively solved by fitting a double pole fuse inside the lamp cap.

Reviewing the experience of the past twelve months it may be stated with confidence that the behaviour of the coiled coil lamps in the hands of the consumer has been exceedingly satisfactory, as many millions have been put into service, and the number of complaints received has been negligible.

Improvements of a far-reaching character have been made in the design of projector lamps. A new method of mounting the filament has enabled the filament areas of certain lamps to be reduced; the lamps are also better able to withstand mechanical

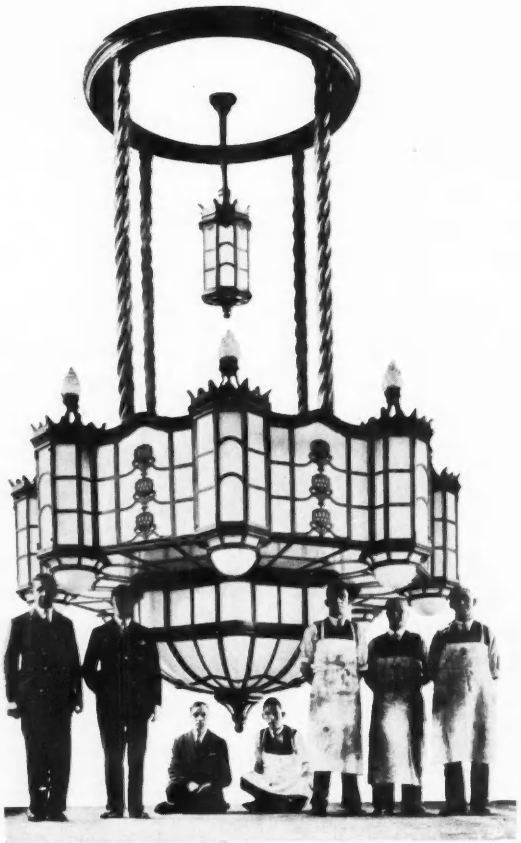


Fig. 35.—Lighting fitting for City Hall, Pretoria, with the seven lighting fitting craftsmen responsible for its production. Total weight 2 tons, 3 cwts.: fitted with 348 lamps having a total wattage of 47,500.

shock. The old and new methods of filament mounting are shown at fig. 32.

Much experimental work has been performed with the object of fulfilling the wish of manufacturers of protection apparatus that high wattage lamps should be made possessing the smallest possible dimensions. Considerable success has been achieved, one example being furnished by the 500 watt lamp used in home cinematograph projectors. This lamp is now produced with a bulb of only $1\frac{1}{4}$ inches in diameter, which compares with the 5 inches diameter of the 500 watt general lighting service lamp.

The efficiency of several sizes of projector lamp has been increased. One instance is afforded by the 30 volt 900 watt class A.1. projector lamp, of which the efficiency has been raised from 22.5 lumens per watt to 28.5 lumens per watt, the average life continuing to be 100 hours.

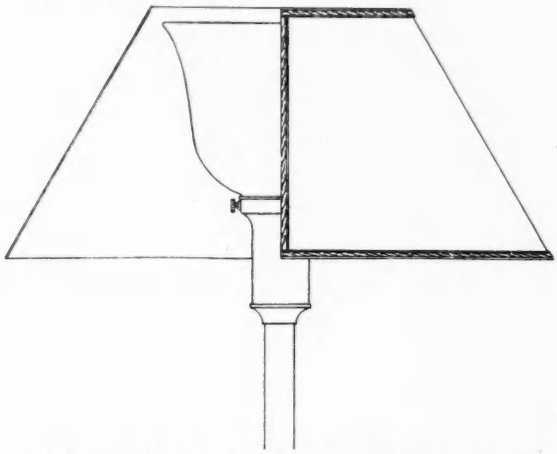


Fig. 36.—Diagram showing arrangement of study lamp.

The range of architectural lamps has been increased by the addition of natural coloured glass lamps, the colours available including white, red, pink, orange, yellow and green. The tubing of the lamp is made of three-ply glass. The innermost layer is clear glass, the middle layer contains the colour medium, and the outside layer is ordinary opal glass. These natural coloured glass lamps are very much better than earlier coloured lamps which had the colour sprayed on the surface. Their introduction proved opportune as it coincided with the development of special weatherproof holders for architectural lamps.

DECORATIVE LIGHTING.

Some years ago little regard was paid to the lighting efficiency of decorative units whether of period or modern design; in consequence the growing demand for "more light" led to the installation of enclosed diffusing units of very much higher efficiency in such places as big stores, offices, hotels and similar buildings. During the last year or two, however, the pendulum of opinion in this matter has tended to swing back, and there has arisen a feeling that lighting efficiency might possibly be assuming too great an importance at the expense of decorative effect. It is now realized that decorative effect and illumination efficiency are not necessarily incompatible, and that it is possible to design fittings in modern or period style giving full play to the artist, without appreciable sacrifice of overall lighting efficiency. As a result greater use is being made to-day of decorative fittings. This change has been made possible by the introduction of higher efficiency glassware, and by the greater knowledge gained of

Fig. 37.—Fittings of special design installed in the Midland Bank, King Street, Manchester.

the art of controlling light so as to distribute it to the best advantage. A typical example of this trend in illumination is furnished by the installation shown at fig. 33.

Such change as there has been in the style of lighting fittings employed is in the direction of large units of relatively low surface brightness in the form of troughs, laylights, and the like, suspended a short distance from the ceiling rather than set flush into it (see fig. 34). In domestic lighting fittings of the modern style, the tendency has been to use softer lines, curves taking the place of the cubist styles which were so popular a few years ago. Another advance in domestic lighting has been the greater use of luminous decoration in private houses, *e.g.*, indirectly lighted niches, glazed wall panels, and similar lighting devices designed more with a view to giving a decorative effect than to increasing the actual illumination.

Indirect lighting continues to grow in popularity for all purposes, but it is more generally recognised that indirect lighting as the sole means of illumination is liable to be monotonous, and must be relieved with some kind of decorative fitting or deliberately contrived high lights. The architectural lamp, either by itself or in conjunction with suitably designed metal backgrounds, is extensively used as a direct decorative light medium in white and various colours. It has also found a considerable application for use in cornices, particularly where space is limited and it is impossible to install efficient reflecting equipment.

Fig. 38.—An example of interior neon lighting—Bobby's Sunshine Restaurant, Bournemouth.

Of considerable interest is the fitting shown in fig. 35, which is one of the largest ever produced. The total weight of the fitting is 2 tons 3 cwt., and it is illuminated by 348 lamps with a total wattage of 47,500. The fitting is installed in the City Hall at Pretoria.

Amongst smaller lighting fittings mention should be made of a new form of table lamp (fig. 36), designed to give really good illumination for such purposes as sewing and reading. The features of this lamp are that it gives illumination of a specified minimum intensity over a relatively wide area in the immediate neighbourhood of the standard, and at the same time directs a large proportion of light upwards on to the ceiling so as to prevent the possibility of unduly harsh shadows where the direct light from the underside of the shade falls off rapidly. Another feature of this lamp, which is generally described as a study lamp, is that from normal positions of view no unduly bright light, which might cause glare, can be seen either above or below the shade.

INTERIOR NEON LIGHTING.

The most outstanding advance during the year in decorative lighting has been the introduction of improved types of neon tubing which can be used to great advantage for interior illumination. Generally this type of lighting comprises a combination of red neon tubing with one or more colours of the highly efficient and decorative "Cleora" tubing. The quality of the light given by such combinations is extremely pleasing and, if desirable, can be varied by the use of dimming equipment.

This lighting medium can be applied first, as a direct visible source of illumination, for which purpose its low surface brightness combined with high efficiency makes it particularly suitable. It can also be used in conjunction with decorative glassware either in the form of self-contained ceiling or wall mounting units, or behind laylights, flush wall panels, etc. As

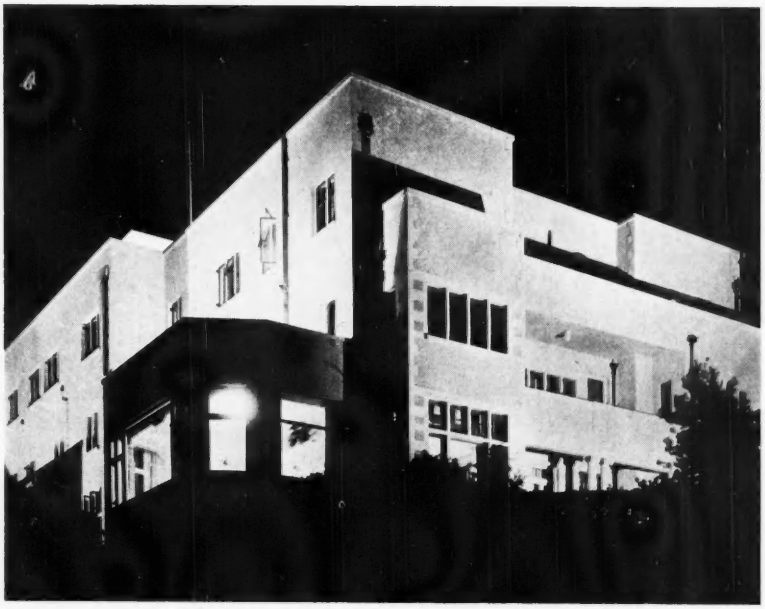


Fig. 39.—" Osira " high pressure mercury lamps are used for floodlighting the Harbour Heights Hotel, Bournemouth.

a third method of application, extremely pleasing indirect lighting effects can be obtained from suitably designed coves (fig. 38).

FLOODLIGHTING.

Extensive floodlighting schemes were undertaken all over the British Empire in connection with the Silver Jubilee of King George V. and Queen Mary. In addition to many other installations, the G.E.C. was entrusted with the floodlighting of Buckingham Palace and the Victoria Memorial, Windsor Castle and Hampton Court Palace. Altogether nearly 7,000 of the company's high wattage floodlights were first put into use during the

Fig. 41.—Floodlighting of Grosvenor Gardens, Chester.

Fig. 40.—Offices and fountains of the Metropolitan Water Board, Rosebery Avenue, London, floodlighted in colour.

period of these celebrations in England and in British Territories overseas. The majority of these floodlights were of standard design, but a limited number of short service units were also manufactured for the occasion. Of these, a general purpose type of floodlight embodying a chromium plated reflector has been permanently added to the standard range of units. Colour floodlighting with "Osira" colour floodlighting lamps played a big part in the celebrations, a prominent scheme in which they were employed being for the lighting of the west and south fronts and the gardens of Hampton Court Palace.

A feature of floodlighting has been the greatly increased number of installations where the possibilities of garden and water illumination have been exploited. For this purpose, "Osira" floodlights, both of the high pressure mercury and colour floodlighting types, as well as tungsten floodlights with colour screens, have been extensively employed, the former units being particularly suitable to show foliage and flowers to the best advantage. Self-contained illuminated fountain units have also been designed. In connection with plant cultivation a reflector has been designed for use with the red "Osira" lamp, while further new floodlighting equipment includes a unit based on the use of the 250 watt line filament horizon type lamp. This unit gives a wide spread of light in the horizontal plane with very little vertical spread. It is therefore particularly suitable for the illumination of ground over a wide area for protective purposes in order to prevent the approach of unauthorised persons. Over a hundred of these floodlights were supplied for this purpose to the Iraq Petroleum Company for use on the Iraq pipe line. This unit may also be used for the underwater lighting of swimming baths, where the wide flat spread of light ensures even illumination over the whole surface of the water without the shafts of light which are an unpleasant feature of other forms of concentrated beam floodlights.

A floodlighting unit has been developed burning the "Osira" high pressure mercury lamp horizontally. This arrangement enables a light distribution to be produced which is particularly suited to the illumination of building fronts, when the offset of the units is limited. Burning the lamps horizontally necessitates the use, under the lamp, of a magnetic deflector which will produce the required deflection with any lamp which may be used over the full range of normal voltage fluctuations.

This particular floodlight can be tilted over a range of angles, and the deflector is therefore suspended in a gimbal mounting so that it remains beneath the lamp whatever the tilt of the reflector unit.

The special design for a diffusing unit for interior lighting which has a more concentrating distribution than the ordinary opal diffusing globe has been applied to the 100–150 watt and 300 watt sizes. These sizes of unit also incorporate the heat-dissipating canopies which reduce the flexible temperature to a safe value.

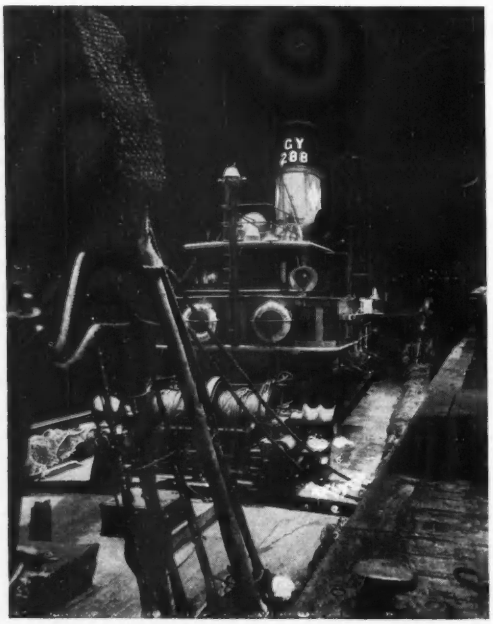


Fig. 42.—A trawler being coaled at Grimsby Fish Docks under a special system of floodlighting.

INDUSTRIAL LIGHTING.

The use of the high pressure mercury lamp in industry has been greatly extended. Its applications in this field were dealt with adequately in the last issue of this Journal, so that further reference here is unnecessary.

For use at the coal face and in other positions where an easily removable flameproof lamp is required, an automatic safety type of plug-connected flameproof fitting has been designed. This fitting (fig. 44), embodies automatic safety devices when used with a suitable type of cable so that sparking at the plug terminals is quite impossible, and by means of a pilot circuit, if the connecting cable is damaged the circuit breaker is automatically tripped before sparking due to short circuit can occur. A further increase in the flameproof range includes a flameproof hand lamp also designed for use with a screened cable which prevents sparking when the cable is damaged.

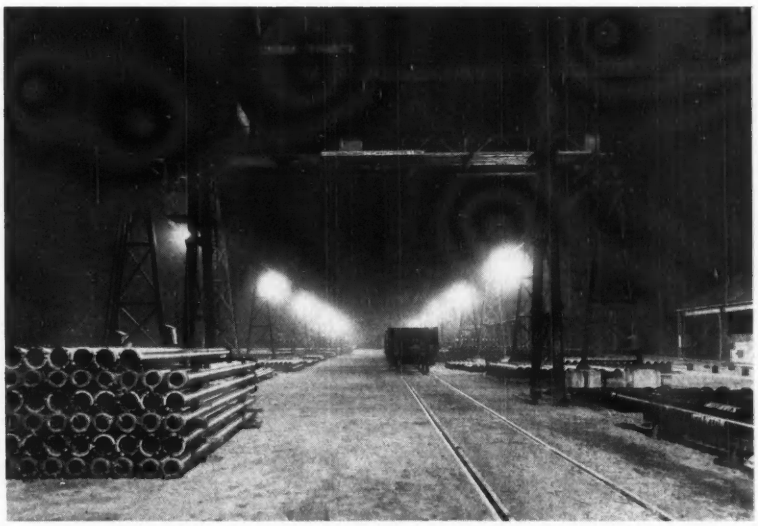


Fig. 43.—"Osira" lighting in the yards of Stanton Iron Works.

SPECIAL FITTINGS.

The most prominent development in the manufacture of special purpose fittings has been the complete re-design of the hospital operating theatre fitting. The basis of the new design was an improved system of light control developed at the Research Laboratories. Lighting intensities far in excess of those previously obtained have been realised without any sacrifice of the general shadowless quality of the light. Improvements have also been introduced into the methods of focussing and accessibility for maintenance and re-lamping purposes.

Other interesting fittings produced include an art school fitting allowing universal movement of the reflector over a very wide area, and also a 24 kW boxing ring fitting complete with raising and lowering gear, designed for the new Ice Rink and Stadium at Earls Court (fig. 45).

AERODROME LIGHTING EQUIPMENT.

Tests in accordance with British Standards Specification No. 563–1934 (Aviation Lighting

Equipment) have recently been undertaken at the Research Laboratories. Such units as boundary lights and obstruction lights, have been examined for compliance with the colour and intensity requirements laid down in the specification.

The aerodrome lighting equipment supplied to the Croydon Aerodrome presents so many features

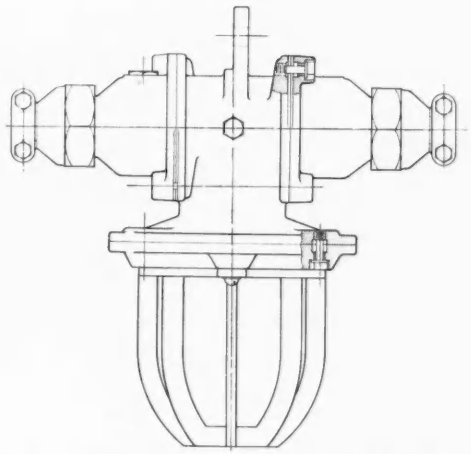


Fig. 44.—Flameproof plug-connected lighting fitting for use at the coal face.

of interest that an article descriptive of the installation is planned for the next issue of the G.E.C. Journal. Work of a pioneer character is also being undertaken in connection with equipment for the aerodromes on the Karachi-Rangoon route. It is hoped that a description of this scheme also will be published in these pages.

A new boundary light has been designed in which the stem is a white cone clearly discernible by day. At night this cone is illuminated by light reflected downwards from the lamp at the top, one lamp sufficing for illuminating the boundary light proper and the cone skirt. Another feature is the making of the conical stem in two pieces, which, in the event of the fitting being broken, telescope together so that damage is reduced to a minimum. Lights of this type are being installed at the twelve aerodromes on the Karachi-Rangoon air route, and also at a number of aerodromes in this and other countries.

A refinement has been added to the wind direction indicator which, when the wind speed is less than 3 miles per hour, returns the indicator to a predetermined position which can be set to indicate the best landing direction for the aerodrome in question. Innovations have been introduced in landing floodlights; for instance in the 9 kW 3-light shadow bar floodlight the suspension of the mirrors has been re-designed so that when the floodlight is being used as a beacon, they can be tilted about an axis inclined at 30 degrees to the normal axis. This produces a beam of light which is visible to aircraft at all angles. The Air Ministry has erected one of these beacons at Shar-Jah in the Persian Gulf, and others will be employed along the Karachi-Rangoon route.

The beam candle-power of the 9 kW 9-lamp landing floodlight has been considerably increased by improvements in the design of both the lamps and mirrors. A new 6 kW 6-lamp landing floodlight (fig. 49) designed for Croydon Aerodrome was tested by the Royal Aircraft Establishment after installation and found to give a maximum beam candle power of over a million beam candles.

The manufacture of rotating route beacons (fig. 50a) is now undertaken. They are designed for installation at intervals on long cross country routes. Four will be employed on the Karachi-Rangoon Air Route.

The new Air Ministry Regulation that obstruction lights must be duplicated has necessitated the introduction of a two-light obstruction light fitting (fig. 50b). The selection of a design having two separate fittings instead of embodying the two lamps under one globe was made because where two lamps are mounted under the same red cover glass, it is impossible to see from the ground whether one of the lamps has failed.

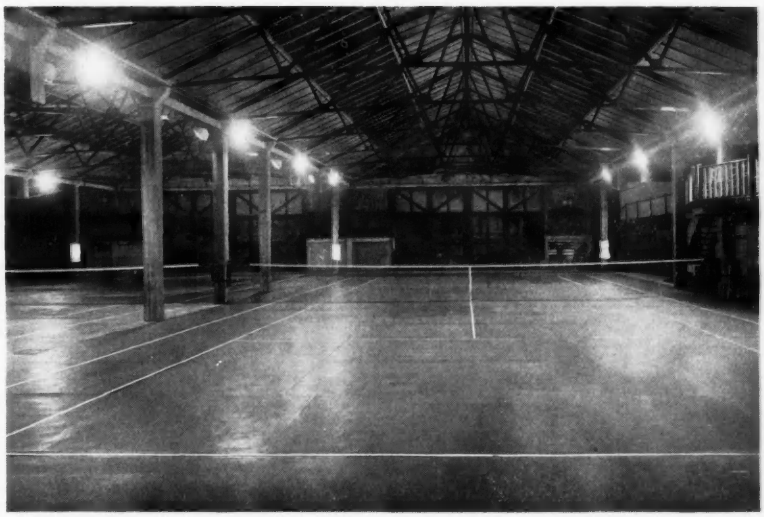


Fig. 45.—An example of indoor tennis court lighting—installed for the Southdene Sports Club, Middleton, Bognor Regis.

STREET LIGHTING.

Public interest in street lighting has been

intensified by the Ministry of Transport's efforts to reduce accidents on the roads. The importance with which good street lighting is regarded by the Ministry of Transport has been made clear by the Interim Report of a Departmental Committee on Street Lighting issued in September, 1935. This report, in its references to street lighting visibility as a function of road brightness, indicates the important revision

(By Courtesy of "The Times.")

Fig. 46.—Lighting of the Guildhall, London, during the Silver Jubilee celebrations.

of street lighting technique largely brought about by work at the G.E.C. Research Laboratories, of which results were published in this Journal.[5]

Further progress has been made in the investigation of light distribution from a street lighting lantern to produce the best road brightness and consequently visibility. It has been demonstrated that the distribution already provided by the lanterns designed for high pressure mercury vapour lamps approaches this optimum distribution more closely than earlier types of street lighting fittings in which the distribution is designed primarily to produce even illumination on the horizontal plane.

The revised street lighting technique just referred to has created the need for some means of measuring the actual brightness of the street as viewed by the road user. The steps taken to this end and the results achieved are described on page 49.

Prolonged investigations have been made of the optimum form of filament for incandescent lamps used in various lighting fittings. It has been found that in standard refractor and reflector fittings, as used for street lighting, dock lighting, etc., the vee-filament gives the most satisfactory results. This type of lamp has therefore been standardised for this work.

The light distribution and road brightness given by the optical system of the Watford and Lewisham lanterns have proved extremely effective in practice, and modifications to lanterns of this type have taken the form of changes in decorative design rather than modification to the optical principles. One such modified design, the "Birchfield" lantern, is shown at fig. 51.

The use of electric discharge lamps for public lighting has increased at an even greater rate than was anticipated. The position in the London area was effectively summarised in a paper read before the Association of Public Lighting Engineers in September.[6]

Fig. 47.—Westminster Hall, London, equipped with a system of lighting to reveal the architecture of the roof.

Some idea of the extent to which this form of lighting is in use may be gained from the number of "Osira" units in certain areas, as given in the following table.

Croydon ..	539	Tonbridge Wells	217
Lewisham ..	404	Birmingham ..	295
Romford ..	207	Blackpool ..	201

CLEORA TUBING.

The importance of the use of neon lighting for indoor use has already been referred to. This

5. G.E.C. Journal, Vol. VI., No. 2, p. 67.

6. "Developments in Electric Lighting in London," by W. J. Allbright, A.P.L.E., September 10th, 1935.

development was made possible by collaboration between the Research Laboratories and Claude-General Neon Lights Ltd., an associated enterprise of the G.E.C. A superior form of Cleora tube can now be produced, and this is used in combination with special red neon tubes. This method of illumination can be adapted also to exterior work, in which connection the new system is particularly applicable to restaurant, showroom, store and cinema lighting generally, but actually its range of application is quite unlimited. Already several installations have been completed.

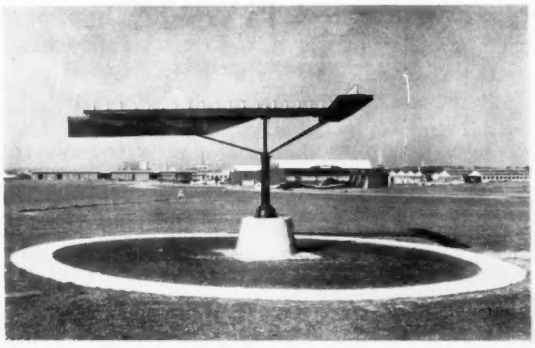


Fig. 48.—Illuminated wind direction indicator at Croydon Aerodrome.

Fig. 50 (a).—Aerodrome air-route beacon of the type to be used on the Karachi-Rangoon Air Route.

ARTIFICIAL DAYLIGHT FITTINGS.

"Claudegen" daylight tubing has been adopted by many industries where complete constancy and accuracy of colour matching is of vital importance. In addition to the portable type of unit, an overhead suspended unit of a type suitable for bench work has been standardised, while complete overhead installations can be carried out to meet individual requirements.

In conjunction with this type of daylight illumination, but for use where complete constancy is not of such vital importance, a range of fittings from 100 watts up to 1,000 watts employing tungsten lamps in conjunction with "Lamplough" daylight glassware has been introduced, while for purposes where colour matching is not involved but where a slight addition of blue light is needed to offset the high proportion of red in the normal tungsten lamp, a range of reflectors using Wedgwood blue glass has been introduced. This type of fitting is particularly suitable for the lighting of drawing offices, printing establishments and similar situations. When used in conjunction with daylight blue lamps, a very fair daylight colour rendering can be obtained sufficient for normal retail sales purposes.

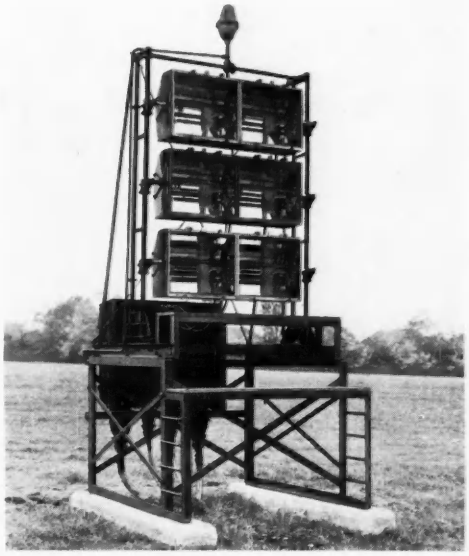


Fig. 49.—One of the 6 kW aerodrome landing floodlight installed at Croydon Aerodrome.

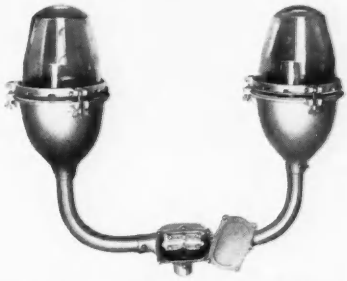


Fig. 50 (b).—Two-light obstruction light fitting for aerodromes.

NEON SIGNS.

Neon signs are in great demand for advertising purposes. One such sign recently installed is shown at fig. 52. Red, blue and green tubing is effectively employed.

An impressive sign is that advertising Kraft cheese at Hayes, Middlesex. The principal words

are in letters ranging from 10 ft. 6 inches to 3 ft. 6 inches. Most of the sign is bright red tubing.

Fig. 51.—"Birchfield" lantern for use with "Osira" lamps.

CABLES AND CABLE MAKING MACHINERY.

The development of an entirely new type of lead extruding machine by Pirelli-General Cable Works,[7] Ltd., has been referred to previously in this Journal.[8] Its advantages over presses hitherto used for lead sheathing cables were then outlined. This machine (fig. 53) has been developed further, and the successful results achieved constitute one of the most important of recent advances in the cable industry. With intermittently operating presses, as used hitherto for lead sheathing cables, it was not possible to obtain a sheath free from welds or seams. This constituted a source of weakness to which may be traced the responsibility for 90 per cent of the cable breakdowns which occur to-day.

The new machine is continuous in operation and produces sheathing absolutely free from seams or welds, therefore its importance can hardly be exaggerated. It has already been used for the sheathing of large quantities of cable, including many miles of 66 kV and 132 kV oil-filled cable.

The machine is now manufactured on a commercial basis in the Pirelli-General Works at Eastleigh, and already orders for it have been placed by other cable makers. It is made in three sizes, namely, large, for sheathing cables up to 5 inches in diameter; medium, for cables up to 3 inches in diameter, and small, for cables up to $1\frac{1}{2}$ inches in diameter.

An improved lead melting pot and an automatic lead ingot handling plant for use with the extruding machine have also been developed in the period under review. The new lead melting pot has a capacity of approximately 2 tons, and is made of a special heat resisting alloy, mounted on a cylindrical shell lined with fire-brick. The pot is gas heated, and the temperature is thermostatically controlled. The casing above the pot is provided with a special flap door, which is opened and closed automatically for feeding purposes when the pot is used in conjunction with the ingot handling plant. Doors are also provided to enable the pot to be hand-fed if desired.

The lead ingot handling plant (fig. 54) is designed to feed the melting pot automatically with the correct amount of lead. This amount is governed by the output from the press. The plant comprises a horizontal conveyor and an elevator. After the conveyor tables have been loaded with lead the plant is completely automatic.

For the Central Electricity Board 50 miles of 132 kV oil-filled cable is to be laid in London. This is of particular interest, having regard to the fact that the first 132 kV oil-filled cable laid in England was manufactured by Pirelli-General for installation in London. The selected station now in course of erection at Fulham is to be connected to the C.E.B. sub-station at Marylebone by 66 kV oil-filled cable.

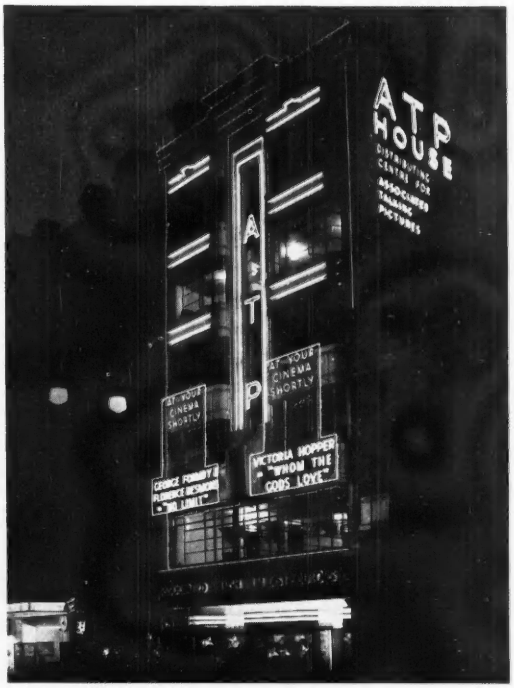


Fig. 52.—Neon sign lighting in red and blue tubing with green outlining on the London Offices of Associated British Distributors, Ltd.

The installation of this cable is in course of progress, and it is noteworthy that it has a copper section of 0.4 sq. in., which is the largest in the world for 66 kV cable of this type.

7. Patent Nos. 429981, 430006, 418078; other patents pending.
8. G.E.C. Journal, Vol. VI, No. 1, p. 35.

Plant has been installed at the Eastleigh factory for the manufacture of all tanks used in conjunction with oil-filled cable work.

During the past year the Post Office have considerably tightened up their specification for telephone cables of the star quad local type; but improvements in design and manufacture have resulted in the specification being successfully met.

Developments in cable for 12 and 24 channel carrier current telephony are continuing, and considerable progress has been made in the design of apparatus for measurements upon this type of cable. An experimental cable of the co-axial type has been manufactured, and is undergoing tests. This cable is for poly channel carrier current telephony (from 100 to 200 channels) and also for television.

Trailing cables for mining use are being improved. They can now be provided with a special form of metal screening and a form of split-main conductor cable, also a metal cage for facilitating repairs to screenings of trailing cables. These devices have been protected by patents.[9] Another construction of cable which has been developed and patented is a canvas housed device for lift shaft work, in which several flat cables are housed and maintained in their relative position by a canvas container.

A range of high and low tension oil resisting compounds suitable for the sealing of cables entering transformers, switchgear, etc., has been introduced. These compounds have further numerous applications.

The new copper rolling mill referred to in this article was put into operation in the early part of the year. It produces all the copper rod for the manufacture of the wires and strip required by both the Southampton and Eastleigh Factories. The mill produces 60 tons of $\frac{1}{4}$ inch rod per shift, and is the most modern copper rolling mill in the country.

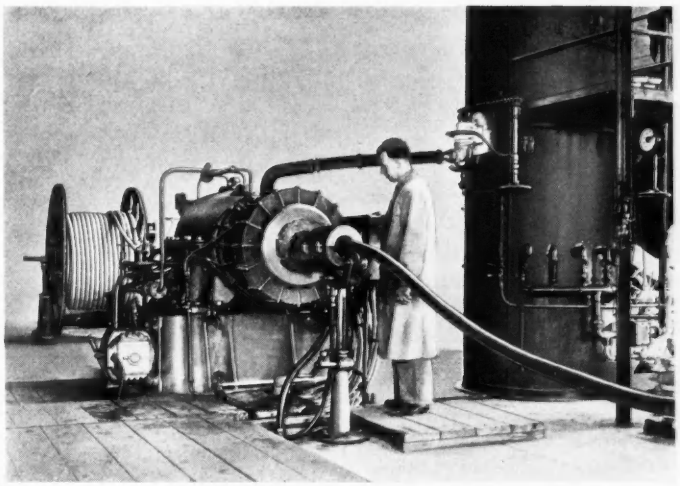


Fig. 53.—New lead extruding machine for sheathing lead cables at Pirelli-General Cable Works.

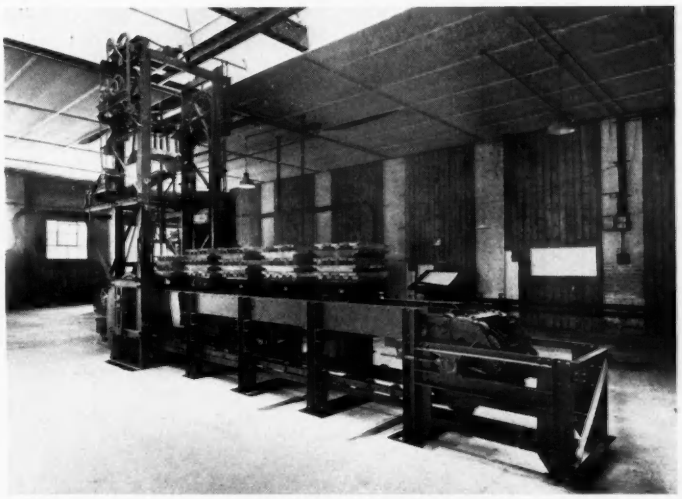


Fig. 54.—Automatic lead ingot handling plant for use with the extruding machine shown above.

TELEPHONY.

The continued increase over a number of years in the application of automatic telephony has brought into greater prominence several factors which determine the efficiency and cost of a system. Operating characteristics of apparatus and space occupied in an exchange have come under review, attention being concentrated on the principal component of the Strowger system, namely, the two-motion selector. As a result a new selector has been designed which shows considerable economy in rack and floor space in comparison with its predecessor, and is capable of stepping at a higher speed. The past year has witnessed the final development stage, and preparations have been made for standardisation.

The importance of the two-motion selector as the device by which a desired line is selected, is at least equalled by that of the relay, since it is through the agency of the latter that control of selector, and indeed of nearly all circuits is effected. Whilst the "major" type relay, fig. 55, has been employed now for some time, it was not until the past year that final development and full production of its companion type was reached. It is thus opportune to review the features of both. The major relay,

9. See page 10.

coded as British Post Office type 3000 was evolved as a standard, and incorporates the respective merits of earlier types, whilst possessing in addition several original features. Reliability and uniformity of

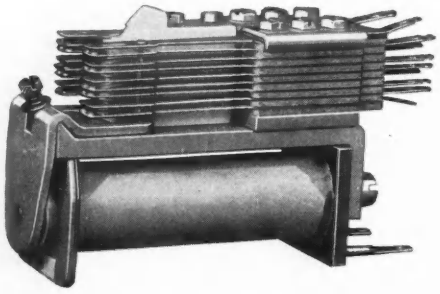


Fig. 55.—"Major" telephone relay.

operation, together with accessibility and ease of adjustment, are characteristics of this relay. A magnetic circuit of low reluctance is obtained by employing knife edge suspension of the armature, together with a special design of joint between yoke and core. In consequence, the flux generated is practically all usefully employed, operation of the relay requiring a minimum of ampere turns.

Fig. 56. — Handset telephone for communication between tenants and service points of flats : operated from A.C. mains.

Since it is found that liability to contact faults from deposits of dust is reduced when relays are positioned so that contact springs are in the vertical plane, this method of mounting has been adopted in the case of the new standard relay. In addition, each spring is fitted with twin contacts, further reducing the risk of contact faults, since the likelihood of both contacts becoming affected by dust simultaneously is extremely remote.

A buffer block situated between the two piles of springs is the principal factor contributing to the ease of contact adjustment. Its provision ensures adequate contact openings, and in addition enables contact pressures to be determined by direct measurement of spring tension. The block is shaped so as to present shoulders on which rest projections on the "fixed" springs of each spring set. These springs are adjusted by means of a simple tool until a tension is imparted such that a given pressure is required just to lift the spring from the shoulder. This pressure is read directly on a gauge applied to the tip of the spring. If the spring is lifted from the shoulder when the armature is operated, it follows that the pressure between the contacts is of the desired value. The white material of the buffer block forms a good background for observing spring movements.

The standard relay is designed for general use, and is capable of really heavy duty, but there are instances in which the conditions do not necessitate the use of a relay of such high performance characteristics. Notably, subscribers' line circuits offer a degree of latitude, since the number of contacts is small and operation comparatively infrequent. A smaller pattern of relay is then permissible, and the "minor" type has been developed for application in such cases. In addition to costing less than the major relay, it presents further economy in that considerably less rack space is occupied. The reduction in size is obtained almost entirely by reason of the smaller dimensions and not at the expense of accessibility, whilst knife-edge suspension, twin contacts and a buffer block are all retained.

There has been an increasing application of these new standard relays, an example in the field of private automatic exchanges being the 10-line unit illustrated in fig. 57. Subscriber's line circuits incorporate minor relays, the common equipment comprising relays of the major type. In addition to being the first unit of its kind to employ the new type relays for establishing all connections, this P.A.X. is noteworthy in that it is designed for operation from A.C. mains.

One of the principal claims to attention of another telephone system developed during the year is that this also is designed for operation from A.C. mains. The system

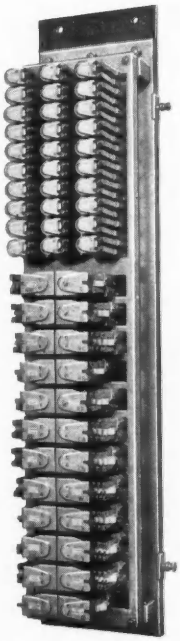


Fig. 57.—10-line all relay P.A.X. unit for operation from A.C. mains.

referred to is one for use in apartment flats in order to give a rapid and convenient means of communication between tenants and service points. A new telephone instrument (fig. 56) for use in this system has been designed, and is in keeping with modern ideas of appearance.

Further progress has been made in the general conversion of the telephone system of Great Britain to automatic operation, whilst increasing trunk traffic necessitated new repeater stations and extensions to several others. A new station completed towards the end of the year is that at Kidderminster, an illustration of a portion of the 180 four-wire repeaters initially equipped being given in fig. 58. For Anglo-Irish traffic a new station at Belfast was completed, having initial equipment for 30 four-wire repeaters.

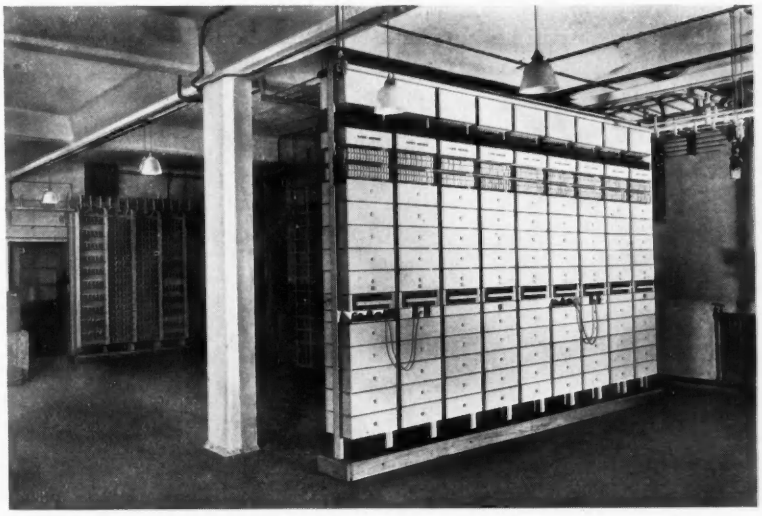


Fig. 58.—Telephone repeater equipment at Kidderminster.

AUTOMATIC VOTE RECORDING.

There are several purposes, other than those which are purely telephonic, to which telephone apparatus is applied. One of these is vote recording. It has long been obvious that the old fashioned method of voting by a show of hands, counting and the manual method of recording in the case of a division was far too slow and unreliable. Clearly an electrical equipment was called for, whose main functions would be (1) to add up and record accurately and quickly votes "for" and "against"; (2) to reduce the time occupied by a division, and (3) to keep a permanent record of how each member voted in a division.

As a result of experiment suitable apparatus was devised and put into manufacture by the G.E.C. in conjunction with its subsidiary, the Reliance Telephone Co., Ltd. The first equipment was installed for the Middlesex County Council at the Middlesex Guildhall, London, S.W. (fig. 59). At the first meeting at which it was used nearly half an hour was saved.

In front of each member's seat is fixed a small pushboard, containing two buttons—one green and the other red, labelled "for" and "against" respectively. On the wall facing the Council Chamber is fitted a cabinet containing a number of coloured lamps, two for each member—one red and one green. The name or seat number of each member is indicated underneath the two lamps which are connected to the pushboard. On the cabinet is also mounted a "Result Panel," of which one half is coloured red and the other green. In addition there are fitted certain keys the function of which is to start, release or test the equipment.

A smaller cabinet fitted only with a result panel and control keys is mounted at the chairman's seat and a further result panel, showing the result of the voting in large figures, is mounted on the opposite side of the wall so that the result can be readily seen by all the members of the Council.

The apparatus for counting the signals from

Fig. 59.—Council Chamber, Middlesex Guildhall, showing vote indicator on left of Chairman's seat and result panel on right. Vote pushes are seen in front of each councillor's seat.

members is mounted on an iron framework and takes the form of a separate automatic switching unit, situated outside the Council Chamber. This uses standard relays and switches of the type

Fig. 60.—Typical re-transmitter installed for the South African Railways and Harbours Board.

employed in connection with automatic telephone exchanges and remote control gear.

When a vote is to be taken, the "vote" key on the control panel is depressed and the members are asked to vote. Each member records his vote simply by depressing the green or red button at his seat, according to whether he wishes to vote "for" or "against" the motion. This lights up the corresponding lamp on the indicator which is associated with the member's seat. The lamp remains alight until the key is restored. Should a member wish to change his vote from "for" to "against," or *vice versa*, he can do so before the count is taken simply by depressing the appropriate button. His previous vote is cancelled and the new vote only will be indicated and subsequently recorded.

When all members have voted (*i.e.*, after a few seconds), the "count" key is depressed, whereupon two figures light up on the result panel or panels ; that on the section coloured green indicates the total number of votes "for" and that on the red section indicates the total number of votes "against." By restoring the "count" key to the "off" position, all lamps extinguish, the figures disappear and the equipment is immediately available for further voting.

When a division is demanded, the recording clerk makes a permanent record photographically or by means of a chart, of how each member has voted. This information is readily available from the colour of the lamp appearing above the member's name.

TRAIN DESCRIBERS.

Another application of telephone apparatus in which progress has been made concerns train-describing. In equipment supplied to the South African Railways and Harbours Board new circuits have afforded considerable simplification whilst maintaining a full range of facilities. The equipment is applied to a busy section of main line, and is designed to enable descriptions to be initiated and sent from a junction cabin, displayed at an intermediate cabin and automatically retransmitted forward for display at a third cabin, transmission of descriptions being effected in both directions. Descriptions are set up when keys are depressed, and are displayed by lamps, the keys and lamps being suitably designated. In addition to receiving and displaying incoming descriptions, and retransmitting these forward, equipment at the intermediate point is arranged to enable descriptions to be interposed or cleared off in order to cover trains entering or leaving the track at that point. A typical retransmitter is shown in fig. 60.

RAILWAY SIGNALLING.

The intense traffic working that is experienced at busy terminal stations presents many problems for solution by the railway signal engineer. In the handling of traffic it is necessary for many shunting and crossover movements to be made which may extend from one side of a station yard to the other ; it follows, therefore, that operation of such an area

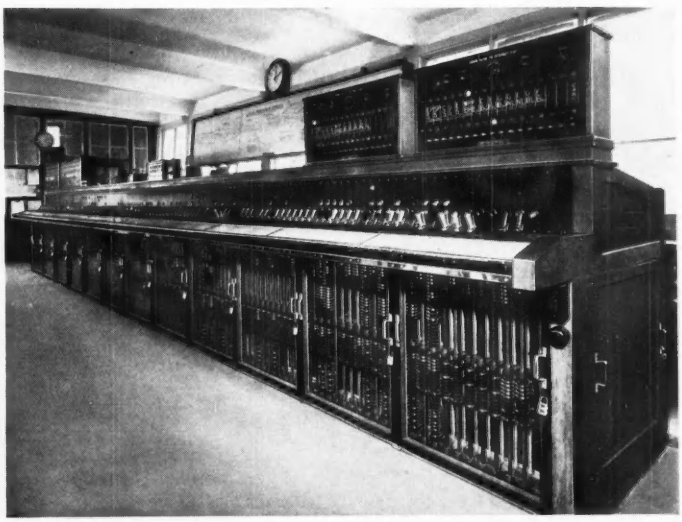


Fig. 61.—Interior of signal cabin at Fenchurch Street Station, L. & N.E. Railway, showing interlocking frame.

is very largely simplified by concentrating the control at one central point. To meet this need with maximum efficiency a new form of power interlocking frame, which is of the all-electric type has been developed by The Siemens and General Electric Railway Signal Co. Ltd.; it is illustrated in fig. 61. This frame which has 140 miniature levers, forms part of a large signalling installation recently completed at Fenchurch Street Station, London, and from it there is now controlled all traffic in and out of the station. The area under control extends some distance beyond the station itself. A feature of the design of the frame lies in the fact that no mechanical locking is employed between levers, all interlocking being effected electrically. Two forced drop locks operated by electromagnets are provided for each lever. Control circuits are taken over sets of contacts operated by each individual lever.

This frame with its associated modern signalling equipment forms part of a remodelling scheme and has enabled the volume of traffic in and out of Fenchurch Street Station to be considerably increased; thus a larger share of London traffic is dealt with.

ROAD SIGNALLING.

A marked advance has been made in the number of installations of the Autoflex system of vehicle actuated traffic control throughout the whole country. In London there have been installed nine large interlinked groups of signals. The most interesting groups are three which have been installed in the Borough of St. Marylebone; two of the groups comprise 20 interlinked crossings and the other group 10 interlinked crossings. The two groups, which are situated in Marylebone Road and Edgware Road, are each automatically regulated by a master controller which includes a traffic integrator (fig. 62).

The traffic integrator is the latest development, and is unique inasmuch as it automatically provides varying cycle times to suit the traffic conditions throughout the day, thus supplementing the functions which the master controller performs of uniting all the respective vehicle actuated local controllers in its group. It should be realized that this involves co-ordinating efforts of controllers which are themselves giving signal indications to the local traffic as required, as well as endeavouring at the same time to give a bias in favour of the main road. In these installations the traffic integrator controlling the master controller alters the cycle time of the main road at 5-minute intervals by taking specimen readings of traffic volume from vehicle detectors placed at key intersections.

Another interesting feature which has been developed in the case of one group is the method whereby the existing Oxford Street signals, which have been installed for some time, are now controlled from an Autoflex master controller.

The improvement in traffic working as a result of the installation of these systems, is such that streets which were previously congested now appear at all times to be half empty.

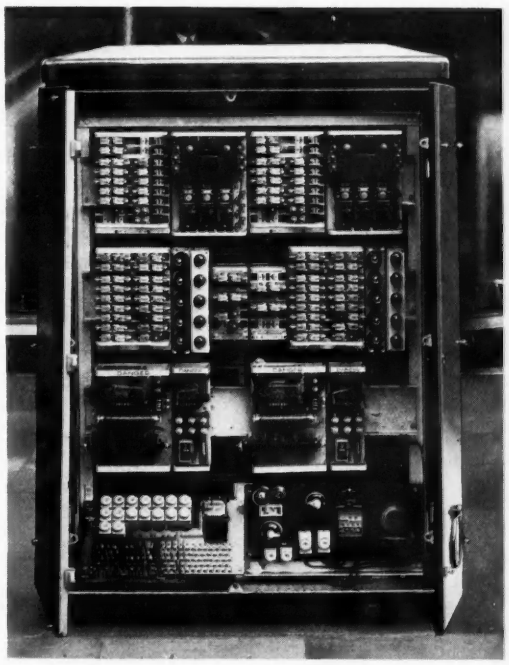


Fig. 62.—Dual master control pillar installed for the Borough of St. Marylebone, London.

MOVING COIL INDICATING INSTRUMENTS.

The miniature instrument range has been completely re-designed with the major object of providing one movement with different lengths of pointer, which will be suitable for all the sizes and patterns of the range. Advantages which accrue from the re-design include uniformity, improved finish and appearance of the movement, better performance, and the production of very low ranges.

An instrument has been produced with the lowest range so far achieved, namely 25 microamperes for full scale. This instrument is intended mainly for service in the laboratory. It can be incorporated with a photo-cell for a very low range of foot-candle measurement.

ILLUMINATION INSTRUMENTS.

The standard illumination meter is a self-contained instrument with range from 0 to 50 foot-candles. Two alternative ranges are now available, one for high intensities, which gives readings up to 250 foot-candles, and another (using the 25-microampere movement) which gives a range of 0–10 foot-candles.

For very low street-lighting intensities a further model is being developed. Instead of a double-pivoted instrument, a double-taut suspended galvanometer is used with a mirror and internal battery and an illuminated scale. The photo-cells are seven in number, and are mounted in a carrying plate which is connected to the instrument by a plug and leads, so that the cell holder may be placed on the ground and the instrument carried by a sling across the shoulder. Three ranges are obtained, (a) from 0 to 0.3, (b) from 0 to 3, and (c) from 0 to 30 foot candles. For use with illuminants other than tungsten filament lamps and gas lamps, corrections are applied by means of a switch and shunts. By this means the instrument is direct-reading also for high pressure mercury vapour lamps and for some other illuminants.

A further new instrument is the road surface brightness meter, the photometric design of which was originated at the Research Laboratories. The purpose of this instrument is to measure not the illumination as received on a road surface, but its brightness as seen by a motorist or pedestrian. This instrument is visual, not photo-electric. It contains a comparison field consisting of an inclined clear glass plate having a row of mirror spots, which reflect a screen so illuminated by an internal comparison lamp that their brightness increases uniformly from one end to the other. The observer views the road surface through the glass plate between the spots and selects a spot the brightness of which is equal to that of the part of the road

Fig. 64.—Multi-range valve voltmeter, mains operated.

surface being measured. A calibrated scale placed against the spots indicates the brightness directly in equivalent foot-candles. The total range is from 0.002 to 8 e.f.c. in three stages, the voltmeter scale being marked x 1, x 0.1, x 0.01. A coloured filter can easily be inserted for use with high pressure mercury vapour lamps so that the instrument is still direct-reading, but on a different scale.

ALL-METAL LABORATORY APPARATUS.

The electro-magnetic fatigue tester, described previously in this Journal[11] has now been improved in design in several important respects. The same principle is employed, namely, that of vibrating a test rod or bar electromagnetically at its natural frequency so that a high rate of impulse is obtained. This method enables a complete test to be obtained in a few hours. There are no moving parts with the exception of the test rod itself. The

Fig. 63.—Fatigue tester mains unit.

improved model comprises a mains unit (fig. 63) and a vibrator, but each part has been re-designed for improved performance and greater scope as regards both ferrous and non-ferrous materials.

A new type of tuned relay is used both to trip the gear on failure of the specimen and also, by means of its calibration, to indicate directly the frequency of vibration. The amplitude of vibration is shown by a microscope with a scale calibrated directly in mils. Tables supplied in an accompanying booklet enable the stress to be calculated directly when these measurements are made. An hour meter has been added to this apparatus to show the total number of cycles of stress that have elapsed during the test.

The logarithmic recorder was designed primarily for use with the fatigue tester so as to indicate failure of the bar. This is of use particularly when a number of vibrators are used with similar test rods, each being operated at a different stress. The recorder will register up to six simultaneous tests so that a curve is automatically obtained by joining the extremities of the record lines. It comprises a drum covered with a chart, the whole being rotated electrically on a logarithmic time base so that in the first unit of time the rotation is "x" degrees and in 10 units is "2x" degrees. Similarly for 100 units it is "3x" degrees. In this way a very wide range of time is covered, the accuracy of the short time records being equal to those of long duration. While this recorder is primarily of use with the fatigue tester, it

11. G.E.C. Journal, Vol. VI., No. 1, p. 43.

has other applications to records of various other electrical tests, especially life tests.

The portable level meter is a development of the Ryall direct-reading attenuation measuring set, and has a range of +20db to – 35db on 1 milliwatt in 600 ohms. It is portable and intended for A.C. mains operation or alternatively from batteries. It comprises an attenuation network and a calibrated "logscale" milliammeter. This latter instrument is also available as a decibel meter.

While a telephone suffices as the detector for many A.C. bridge measurements it is sometimes required that the null indicator should be visual instead of audible, particularly for relatively noisy rooms and also in circuits where considerable amplification is required so as to increase the overall sensitivity.

The new amplifier detector is a high-gain unit, due largely to the use of specially quiet valves and Gecalloy toroidal mains and input transformers. The present model is particularly suited to cross-talk measurements, for which purpose it was originally designed.

For most measurements of radio frequency voltage, and for many cases in which the voltmeter must not impose a load on the source of supply, the usual types of voltmeter are unsuitable, and the valve voltmeter becomes practically essential. The multi-range model, fig. 64, developed during the past year, has ranges of 0 – 1 – 2 – 5 – 15 – 50 volts and is mains operated on 200-250 volt supplies, 50 cycles per second. It makes use of a valve employed as an anode bend rectifier, the change in anode current being used to measure the value of the A.C. voltage impressed on the grid-filament circuit. In order to be independent of mains fluctuations a barretter is used and a glow-gap voltage stabiliser provides the necessary anode voltage supply. The frequency error is negligible over the range of 40 cycles per second up to at least 3 megacycles per second and the input capacitance about 10 micro-microfarads.

PROTECTIVE GEAR.

The new regulations of the Institution of Electrical Engineers for the electrical equipment of buildings require that means be provided for preventing a dangerous rise of voltage between the case or framework of apparatus and earth. This is particularly of importance on rural lines, where earth resistances may be high and a fault to the case of any apparatus may lead to a dangerous shock. The "Elf" circuit breaker has been modified so as to act as an earth leakage trip, the contacts being in the main circuit and suitable for current up to 25 amperes at 250 volts, but the trip coil is connected in the earth wire so as to operate if the leakage current reaches 30 milliamperes. To test the operation periodically a press key is provided on the front of the case so that the trip coil is connected to line and earth through a resistance. By this means the protection afforded can be checked daily or as often as required.

A slightly larger double pole breaker is supplied for currents up to 30 amperes, and where still larger currents have to be dealt with, an ordinary circuit breaker with a no-volt coil can be used, and the "Elf" leakage trip coupled so as to interrupt the no volt coil, and thus open the main breaker when a leakage of 30 milliamperes occurs. In all cases, a voltage of approximately 20 is sufficient to force this 30 milliamperes through the trip coil so that operation of the leakage trip is assured, even with an earth resistance as high as 5,000 ohms.

A new thermostat has been designed in collaboration with the consulting engineers and architects for the new London University building, and is of the air or room type. Its case is all-insulated in conformity with modern practice for electric fittings.

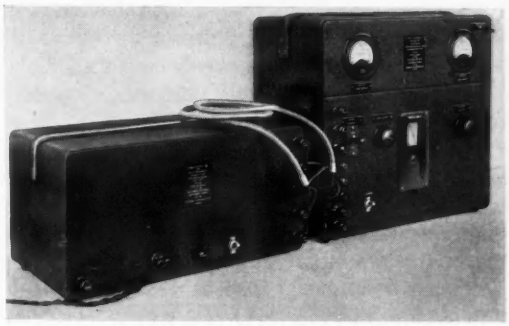


Fig. 65.—Beat frequency oscillator and mains unit.

LOADING COILS FOR TELEPHONE CABLES.

Loading coils have been supplied in large numbers both for the British Post Office and for several colonies. The loading coils are for service on main trunk lines, minor trunk circuits and town cables.

Various carrier frequency components, such as coils and transformers, have been developed and manufactured, and a wide range of testing apparatus and measuring instruments for the carrier and radio frequency range has been produced to meet the demand for compact and efficient testing apparatus for the new developments in line and wireless transmission. For use in conjunction with this apparatus wide use has been made of Gecalloy cores for the whole of the communication frequency range.

RADIO CORES.

Considerable advances have been made in the design and production of Gecalloy radio cores for broadcast receiving sets, and large quantities have been manufactured. The newer types have been

made to a size tolerance of ±0.005" and an effective permeability tolerance of ±2 per cent.

ELECTRICITY METERS.

A recent development by Chamberlain & Hookham Works is a prepayment meter, fig. 66, capable of being actuated by coins of two denominations. It consists of a single phase alternating current meter element geared to a prepayment mechanism, and is arranged for operation by pennies or shillings at will, there being only one coin slot. A coin register is provided and this reads the total amount inserted in pounds, shillings and pence up to a total of twenty pounds. The large pointer on the pence unused dial indicates the amount standing to the consumer's credit. Ten shillings can be prepaid at one time or one hundred and ten pence, after which a shutter closes and prevents further coins being inserted until a portion of the credit has been used up.

When a coin is inserted in the meter it falls into the coin barrel and on turning the handle, a sleeve is caused to slide along the barrel until it engages with the coin. The sleeve is coupled to a gear selector device, and the position of the sleeve when in engagement with a coin determines the gear ratio between the coin barrel and the registering mechanism. Thus the mechanism will be advanced twelve times as far for a shilling as for a penny.

If a coin of incorrect denomination is inserted the mechanism cannot be operated, as the coin barrel cannot be turned. To prevent the mechanism being damaged by attempts to force the handle in these circumstances a clutch is provided in the handle, which slips when excessive force is used. To dispose of the coin which is resting in the coin barrel a button situated on the top of the cover is pressed. This releases the coin, which falls through the barrel into the coin box below.

A view of the mechanism removed from the case and seen from above is shown in fig. 67. To enable the price per kWh to be changed easily, a removable gear unit is fitted, and is shown removed from the mechanism on the extreme left of the illustration. This gear unit slips into position and is automatically located to gear accurately with the counting train of the meter, and also with a differential gear embodied in the mechanism. The gear unit can be exchanged in an instant by an unskilled person without the use of any tools, and the latch is so arranged that it cannot shake loose. The coin box holds two pounds worth of pennies and of course a much larger value of mixed pennies and shillings.

The ordinary prepayment meter for operation by coins of one denomination is now made in a bakelite case, fig. 68. The meter and mechanism are mounted on a metal sub-base, which is screwed to the back of the case. There are no screw threads in the bakelite and all terminals are easily removable. All metal parts fixed to the outside of the case are efficiently screened so that there is no possibility of obtaining a shock due to accidental contact with any live part of the interior. This is a very important point in connection with prepayment meters, as although it is a very rare occurrence for a meter case to become alive, the consequences of such a happening might be serious because the consumer has to touch the meter case when inserting coins.

A new polyphase prepayment meter, of which the interior is shown in fig. 69, consists of a three-phase meter coupled to a standard prepayment mechanism modified by the addition of two single pole switches. The mechanism itself has a single pole switch in the rear, and this is coupled to two additional switches located below the mechanism. Thus the circuit

Fig. 66.—Prepayment meter.

can be opened on all three lines, and the meter can be supplied for use on three-phase three-wire or four-wire systems. This type of meter is particularly useful in connection with small motors, and can be made in sizes up to 25 amps at 440 volts three phase.

The Chamberlain & Hookham summator, in which electrical impulses originating in a number of separate meters are summated in a single instrument has already been fully described in this Journal.[12] A simpler form of summator has now been designed which although not of such wide application as the larger type, is nevertheless of considerable utility. The summation meter, fig. 70, is summating the output of four large generators totalling 200,000 kW and indicates the combined maximum demand on the sets. It consists of a polyphase meter having four separate pairs of series windings acting upon a common rotor. The maximum demand indicator

12. G.E.C. Journal, Vol. V., No. 2, p. 79.

driven from the lower end of the rotor shaft is controlled by a synchronous motor-operated timing element seen in the lower right hand corner of the illustration. A printometer is also used in conjunction with this summation meter, and prints on a chart the actual demand in every 30 minute time interval. A contact making device fitted to the

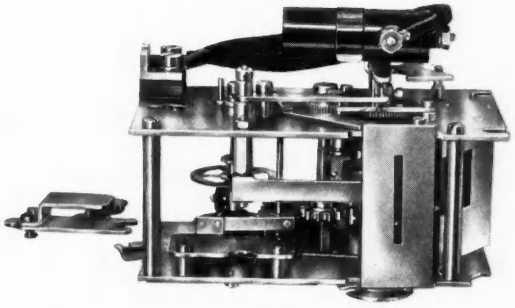


Fig. 67.—Mechanism of prepayment meter.

counting train of the meter, energises the relay seen in the top right hand corner, and passes on impulses from the meter to the printometer. The timing element performs the dual function of mechanically setting to zero the mechanism of the maximum demand indicator every 30 minutes, and also electrically setting to zero the printing mechanism of the printometer. This type of summating meter can be arranged to summate two, three or four separate circuits.

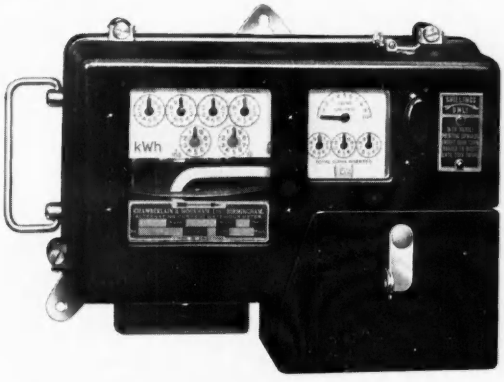


Fig. 68.—Prepayment meter in bakelite case.

The site testing of polyphase meters often involves considerable difficulty and inconvenience, and because of this it is frequently neglected. In the case of high tension consumers it sometimes happens that the plant can only be shut down at a week-end for a sufficient time to connect in the testing instruments, and this may involve disconnection of leads behind the metering panel. Temporary connections have to be made quickly, and current transformer secondary circuits have to be opened in order to connect in the testing instruments. In the case of generator meters the difficulties are greater as the generator may be running for several weeks or even months, and before it is possible to obtain access to the connections the set must be shut down. In order to overcome these objections, testing terminals have been provided, and an improved form of testing terminal block has recently been introduced. A view of this block with cover removed is shown at fig. 71.

The testing terminals are fitted in a moulded bakelite case and when used with a front connected meter the leads enter at the top. For use with back connected meters, terminal stems entering from the back are provided. The leads to the check meter or testing instruments enter at the bottom. The block illustrated is suitable for use with three-phase three-wire or four-wire meters, there being four spare terminals which are not in use in the case of three wire meters. Reading from left to right, there are three current terminals in the red phase, three in the white phase, and three in the blue phase followed by four voltage terminals in the order red, white, blue and neutral. An insulating fillet separates each terminal from its neighbour. It will be seen that three links are provided, each bridging a pair of terminals. When it is desired to insert a check meter or other instrument, the current coils of the check meter are connected between the terminals which are linked together, each of course in the appropriate phase. On removing the links the check meter current coils will now be in series with the current coils of the meter to be checked, without having to interrupt the supply. When the test is completed the links are restored and the check meter removed. If at any time it is necessary to remove the meter from the panel, the secondaries of the current transformers should be short circuited before removing the meter, and this can be done by swinging the links over to the left. This also applies if it is desired to check the meter on the panel with an artificial load. A portable test set complete with artificial load is manufactured, and this can be connected to the testing terminals, enabling a complete test to be made on the meter at all loads and over a range of power factors without disturbing any of the permanent connections.

POTENTIAL TRANSFORMERS.

A potential transformer for use on an 88 kV system is shown in fig. 72. It is an outdoor type transformer, and the system operates with one pole earthed. The core is of the shell type, and the windings are mounted on the centre limb. The high tension winding consists of a large number of coils on bakelite cylinders. Surrounding each layer of coils is a bakelite cylinder, and between this and the next cylinder having a layer of coils is an

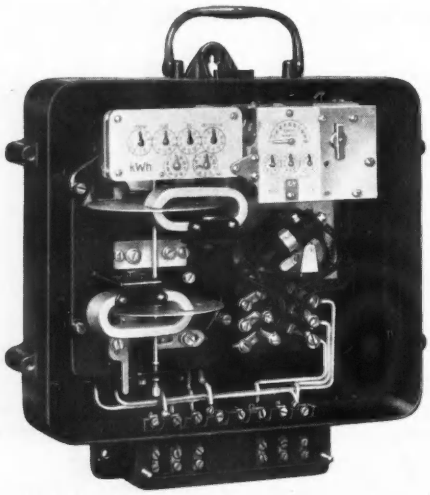


Fig. 69.—Polyphase prepayment meter.

ample oil space which does not contain any coils. The bushing is oil filled and is provided with guard rings, the oil level in the bushing being visible through a window at the top. The ratio of the transformer is 88,000/110 volts, and the rated output is 500 VA Class B. at 50 cycles.

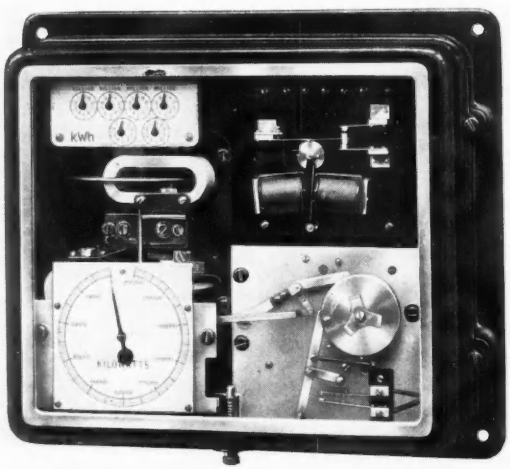


Fig. 70.—Summator meter for summating output of four generators with total output of 200,000 kW.

ELECTRIC HEATING FOR FARMERS.

Owing to the introduction of the Accredited Milk Producers Scheme early in 1935, a large demand has arisen for sterilizing equipment for milking utensils. A range of electric sterilizing chests, with self-contained steam raising equipment, has therefore been made available. Compared with fuel fired boilers, these chests have the advantages of being compact and entirely eliminate the use of fuel, whilst operation is practically automatic. The electrode steam raiser described in the next paragraph is another type of equipment which meets the demand.

ELECTRODE STEAM RAISERS AND CIRCULATORS.

A small electrode steam raiser with maximum rating of 20 kW and capacity of 60 lbs. of steam per hour has recently been introduced. It finds a number of applications, especially on farms and dairies for sterilizing purposes. Sterilizing in dairies is largely carried out at about 212 deg. F., so that the steam raiser has to deliver steam at or just above atmospheric pressure. For this purpose a very simple control equipment gives the required service. To maintain a constant load the water level in the steam raiser is automatically maintained by a float valve, while the electrical equipment consists of a main ironclad switch, contactor and hand reset overloads.

For another class of sterilizing pressures of 20/60 lbs. per sq. inch may be required. In this case the pressure switch operates to open and close the main contactor to maintain a constant pressure of steam in the steam raiser. If the feed water pressure is insufficient, the float valve feeding equipment cannot be used, and a hand operated feed pump is substituted. The capacity of the steam raiser is such that it requires feed about once every half hour, and as the water level falls the average load is maintained by the operation of the pressure switch.

For various other applications such as vulcanizing, temperatures up to 300 deg. F. are required, and a number of equipments suitable for operation at 60 lbs. per sq. inch have been supplied. In such cases a hand operated feed pump is necessary, but the other control gear remains the same as described for operation at 20 lbs. per sq. inch.

ELECTRIC FURNACES.

The application of the Grunewald Process (Vol. III, No. 2, p. 87) to the bright annealing of cold

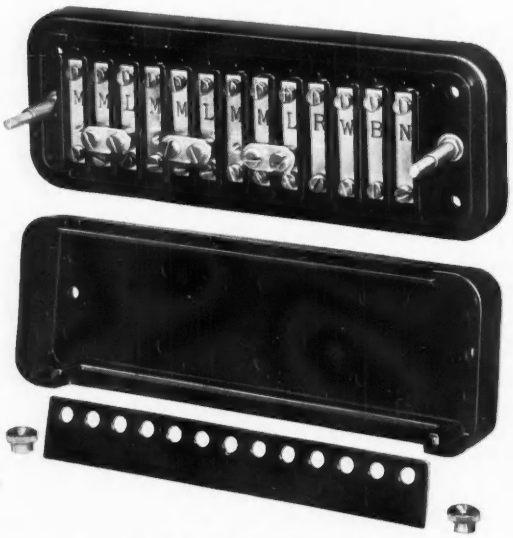


Fig. 71.—Testing terminal block.

rolled steel strip has been considerably extended, and many furnace installations have been completed, of which a typical example is shown in fig. 73. One development of the process has been in connection with the annealing of high carbon steel without decarburisation. It should be emphasized that the Grünewald process is the only method of bright annealing which does not necessitate an artificial gas atmosphere. A modification of the process has been applied to the bright annealing of copper sheets.

Nitriding furnaces have been standardized, and a range consisting of five outputs is available for the surface hardening of special steels and irons by the Nitralloy process.

Attention has been given to a special furnace designed for the melting out of babbit metal from bearings for re-metaling purposes. Several furnaces of this type have been made for the Indian State Railways.

An important development which has been made involves the use of centrifugal fans in connection with forced air circulation furnaces for low and medium temperatures.

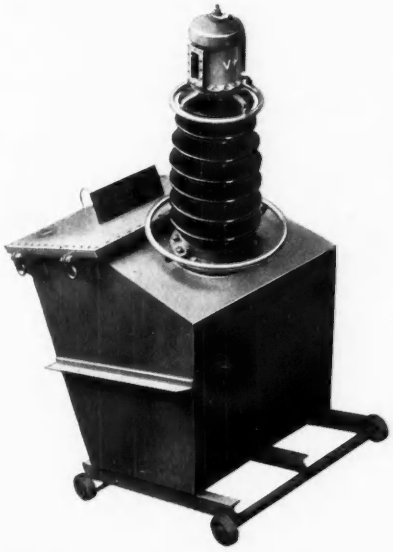


Fig. 72.—88 kV potential transformer.

INDUSTRIAL HEATING APPARATUS.

A new type of convector heater has been developed which gives a high degree of convected heat. Its construction is shown in fig. 75. The actual heating elements, which are of the low temperature rod type, are placed in a central duct open at the bottom and communicating with the air through the grille at the top front of the heater. Hot air, therefore, passes over the elements through the duct and is projected outwards and forwards through the grille. This main duct is surrounded by a series of subsidiary ducts through which air at lower temperatures is convected, the final result being that the outer case of the convector, apart from the actual grille through which the air emerges, remains remarkably cool.

Cordless electric irons have been introduced to meet the objection which has been raised by the laundry trade that the cord on the irons is a hindrance in ironing, and that trouble is experienced by the flex wearing. The complete unit (fig. 74) consists of a board fitted with runners and equipped with switch, pilot lamp and fuse. With a one way board, two irons are supplied; with a two way board, four irons, and so on. Thus while one set is being used the other set is being heated. Three different sizes of board are made, one for the various sizes of laundry iron, one for tailoring irons and one for polishing irons.

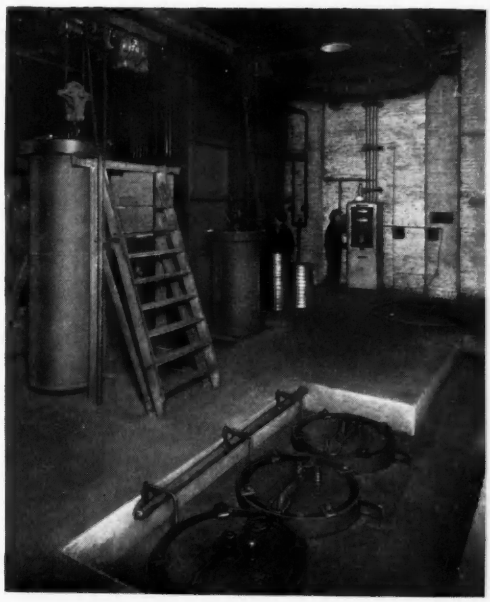


Fig. 73.—"Grünewald" furnace installation at the works of Sanderson & Newbold, Ltd., Sheffield.

INDUSTRIAL COOKING EQUIPMENT.

A large number of complete galley equipments have been installed during the year, prominent amongst these being the equipment for the new P. and O. liner "Strathmore," referred to earlier.

From the experience gained from installations on board ship, it has been decided to manufacture all industrial type ranges and boiling tables with what has hitherto been known as the "Marine type" hob fitted with anti-drip hot plates. This hob was designed to protect the leads and connections to the hotplates from spilt fats, swillings, etc. The hotplate is totally enclosed, and rests on

the main hob, while a false hob fits on top of this with the top flush with the top of the hotplate. A protecting flange on the hotplate fits over a projecting flange on the hob, and thus completely encloses the leads and connections.

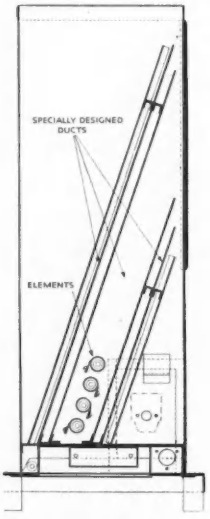


Fig. 74.—Diagram of convector heater.

DOMESTIC COOKING.

Progress in domestic cookers has largely centred upon the electric thermal storage cooker. This subject was dealt with comprehensively in the last issue of the G.E.C. Journal and further reference here is unnecessary.

The efficiency of the standard range of electric

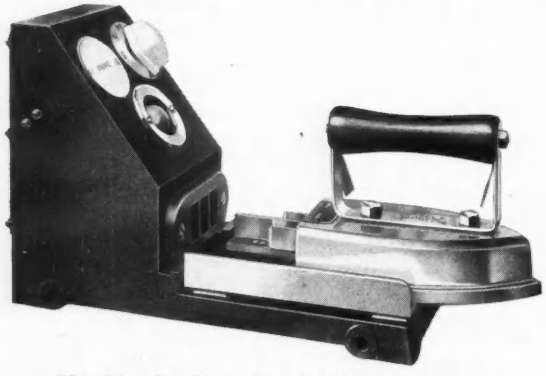


Fig. 75.—Cordless electric iron equipment.

cookers has been improved due to increased loading of hotplates. New models supplementing the range have been introduced, in order to meet the demand for a smaller cooker suitable for bungalows, flats and small houses.

RADIO SETS.

One of the most important features in the manufacture of radio sets during the past year has been their increased reliability, brought about by careful attention both to circuit design and mechanical layout.

Improvement in the efficiency of "straight" 3-valve sets has been effected by the employment of tetrode detectors and high efficiency stranded wire coils in radio frequency circuits. In the mains receiver class, the introduction of a high slope output pentode in both the "straight" and the superheterodyne type of 3-valve receivers, has largely increased their efficiency. The circuit of the latter consists of a frequency changer, I.F. amplifier and a double diode output pentode.

Improved reaction circuits in the "straight" receivers has enabled the sets to be handled with the maximum of ease, the reaction control having rarely to be touched. The battery set also incorporates a battery economiser circuit which enables the battery to be used when run down to quite a low voltage.

In the superheterodyne class, the "Fidelity" A.C.5, which has been developed, will receive strong local stations free from high note loss.

The average receiver, if it is to be free from interference, does not reproduce frequencies above 4,500 cycles, whereas the new circuit makes possible reception up to 7,500 cycles. This set also has a new muting circuit which removes the background noise generally heard when tuning a set between one station and another.

An addition to the range of receivers is a car radio equipment capable of receiving a wide range of stations.

A sidelight is thrown on the growth of radio activities by the necessity for the addition of still further testing equipment at the works.

EMPIRE BROADCASTING.

One of the most popular services of its kind is the British Broadcasting Corporation's Empire transmission from Daventry. During 1935 the Gold Coast followed the example of Sierra Leone in installing a relay service to receive this Empire programme and distribute it over wires to subscribers to the service. Two short-wave receivers are employed, together with power output amplifiers. The amplifying stages initially installed are capable of serving some 1,500 subscribers, provision being made for an increase in output power as and when the number of subscribers increases.

RECEIVING VALVES.

The range of receiving valves for high-frequency and low-frequency use has been extended. Co-operation between the Research Laboratories and the M.O. Valve Works has led to new detector-oscillators, H.F. pentodes and diodes for high frequency amplification, while in the L.F. section new triodes for voltage and power amplification are available.

The new detector oscillators are triode hexodes and are known as types X41 (4 volt heater) and X31 (13 volt heater for "universal" receivers) respectively. They offer improved performance over previous detector-oscillator valves, owing to their higher impedance, and since the interaction between the triode and the hexode section has been reduced to a negligible amount, they are particularly attractive for use at short wavelengths.

A new H.F. pentode, the W.31, has been introduced into the universal range, while similar valves incorporating diodes, the WD30, and its 4 volt counterpart, the WD40 have also made their appearance. These valves, if employed as intermediate-frequency amplifiers and second detectors, are capable of supplying a voltage for automatic volume control as well as sufficient audio-frequency voltage fully to load the new output pentodes, types N41 and N31. A double diode, the D41, has the advantage that owing to its special heater rating (4 volts, 0.3 amps.) it can be used either in parallel with 4 volt valves, or in series with 13 volt valves in "universal" receivers.

Considering the low-frequency types, one interesting innovation is the A537, a voltage-amplifying triode intended for use in microphone amplifiers or in other positions where very low microphonic noise and valve background noise is essential.

Two types of output valve, the PX25A and DA30 have been developed for delivering large outputs such as are required for public-address and radio-relay equipment. These valves are intended for use in push-pull circuits and were designed on the principles worked out at the Research Laboratories. As a result, the valves deliver an audio-frequency output three times as great as was possible previously with valves of similar size. The outputs are respectively 32 and 45 watts per pair of valves.

In the development of a new high-sensitivity output pentode, subsequently known as the N41, a new form of distortion resulting from secondary emission was observed. This effect has been fully investigated and these valves can now be produced free from the original defect. The power output is about 4 watts, while the maximum grid swing needed is only 4.4 volts. A similar valve for the "universal" range, the N31, has also been developed, while versions incorporating double-diodes and known as the DN41 and DN31 respectively, are intended for those cases in which the use of a separate diode valve is undesirable.

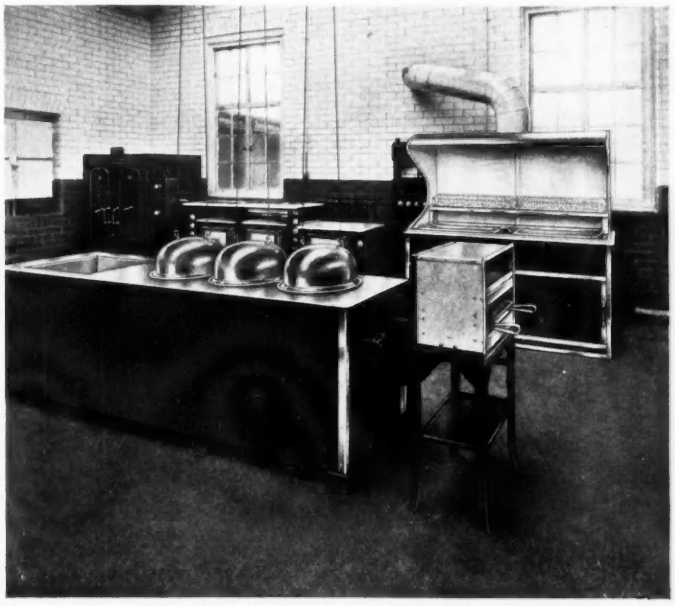


Fig. 76.—Electric cooking equipment at Edge Hill Training College.

PHOTOCELL AMPLIFIERS.

A new design of photocell amplifier, type FDL50, has been introduced, a view with the front of the case removed being shown in fig. 79. It has wide general application both indoors and out of doors, and possesses the advantage of being a most compact unit. Moreover most efficient ventilation is provided. The design of relay employed enables the set to operate in any position.

A photo-cell equipment of more limited application which presents many ingenious features is for

the purpose of switching artificial lighting on or off when darkness approaches or recedes. A view of this equipment is given at fig. 79; two photocell units are included.

The failing of daylight is registered through the photocell and amplifying valve to a large milliampere meter, the needle of which passes through a ray of light shining on to the first photocell equipment. In this case nothing happens until the needle travels further to break the ray of light on the second photocell equipment. When the needle cuts the ray of light on this second photocell equipment the Neon timing device is set in operation, this being arranged to give a fifteen second delay action. The object of this delay is that if within a period of fifteen seconds the milliampere needle falls away again after breaking the second ray of light, the load will not be switched on. This arrangement prevents rapid switching on and off of the load should the needle fluctuate slightly just as the daylight is falling, when the light is at that critical point where a slight variation due to mist or cloud would momentarily allow the needle to fall away after breaking the ray of the second photocell equipment.

If, however, the needle continues to obscure the ray of light on the second photocell equipment for a period exceeding 15 seconds, then a Neon capacity timing device operates the main contactor coil through a relay which switches on the load.

A retaining contact is supplied with the contactor to hold it in contact when the needle falls back upon

Fig. 77.—"Fidelity" all-wave superheterodyne receiver.

the approach of daylight until the ray on the first photocell equipment is broken. When this happens the contactor circuit is interrupted thus switching off the load.

This photocell equipment provides an absolutely definite positive switching on and off of the load, without any flickering.

ELECTRIC HORTICULTURE.

In horticulture, progress has been made with the application of soil heating cable, and a new introduc-

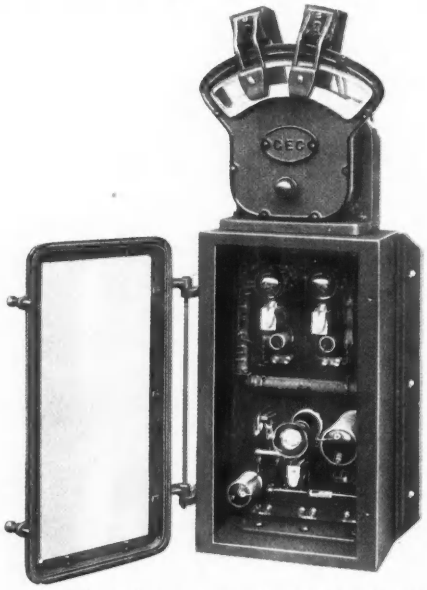


Fig. 78.—Daylight control photocell equipment.

tion is one with a temperature control device incorporated. This constant temperature soil heating cable has a length of 30 yards and a loading of 200 watts, and is particularly applicable to small garden frames, as used by amateurs, and for propagating frames for seedlings and cuttings. A plant irradiator incorporating an "Osira" floodlighting lamp is another new introduction. The red rays of this unit are particularly beneficial for plant culture, and may be used for controlling and stimulating growth.

MINE BELL-RINGING TRANSFORMER.

A mine bell-ringing transformer has been developed, which complies with the requirements of the Mines Department for "intrinsically safe" apparatus. The transformer is designed to step down a given supply voltage to 15 volts on open circuit. The design however is of a specialised nature in that the technical characteristics of the transformer are such that the resulting spark emanating from a short circuit of the outgoing secondary wires, will not cause an inflammable methane mixture to explode. The transformer core and windings are enclosed in a cast iron container which is completely filled with compound, the whole construction providing a sound mechanical unit.

ELECTRIC LIGHT AND INSTALLATION ACCESSORIES.

The enormous extent to which electric lighting and installation accessories are used is frequently

overlooked. There are very few classes of electrical apparatus which are not dependent upon some form of accessory, either as a component or for a control purpose. Thus for every electric lamp, whether for street lighting, industrial lighting, floodlighting, or domestic lighting, whatever its service, a lamp holder is required; electric radiators must be provided with switches, cooker control units need switches, fuses and socket outlets. Innumerable further instances could be mentioned to illustrate the dependence of the electrical industry upon accessories. Therefore continuous development of clocks or radio sets. Such appliances may be connected to this permanently live supply by means of a plug in which a fuse is incorporated.

Another addition to the range of switch plugs is a 15-ampere 3-pin pattern which has provision for a pigmy lamp behind a facetted convex ruby glass giving luminous indication whilst the switch is on.

The introduction of Regulation 201 (C) and (D) by the Institution of Electrical Engineers,[13] permitting a maximum of 10 points to be connected to a final sub-circuit, has increased the demand for 2-ampere socket outlets and plugs in

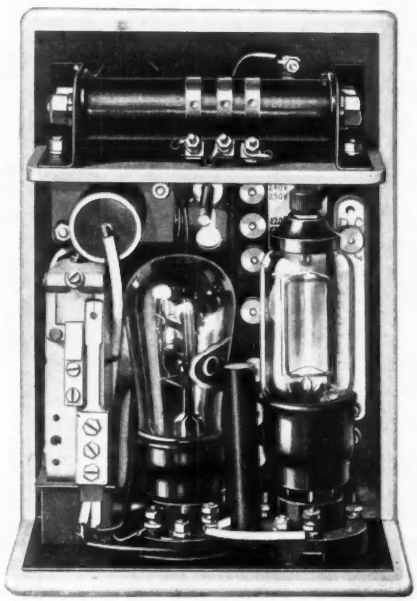


Fig. 79.—New Photocell amplifier.

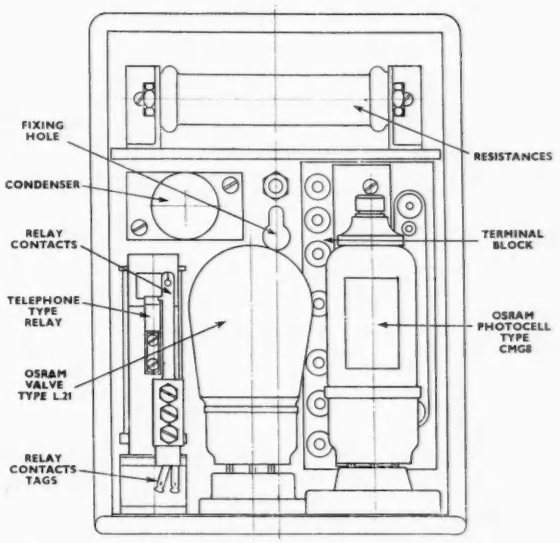


Fig. 80.—Diagram of amplifier shown in fig. 79.

suitable ranges of units is in progress, and reference may be permitted to a few of the more important recent advances.

For secondary lighting systems in cinemas and similar public buildings, a lamp is adopted of different voltage from the main voltage. If bayonet capped lamps are employed for both systems, there is the possibility of inadvertently inserting a low voltage b.c. lamp into a high voltage lamp holder. An Edison screw lampholder with backplate has therefore been designed to fit a standard conduit box in the secondary system, thus preventing interchangeability.

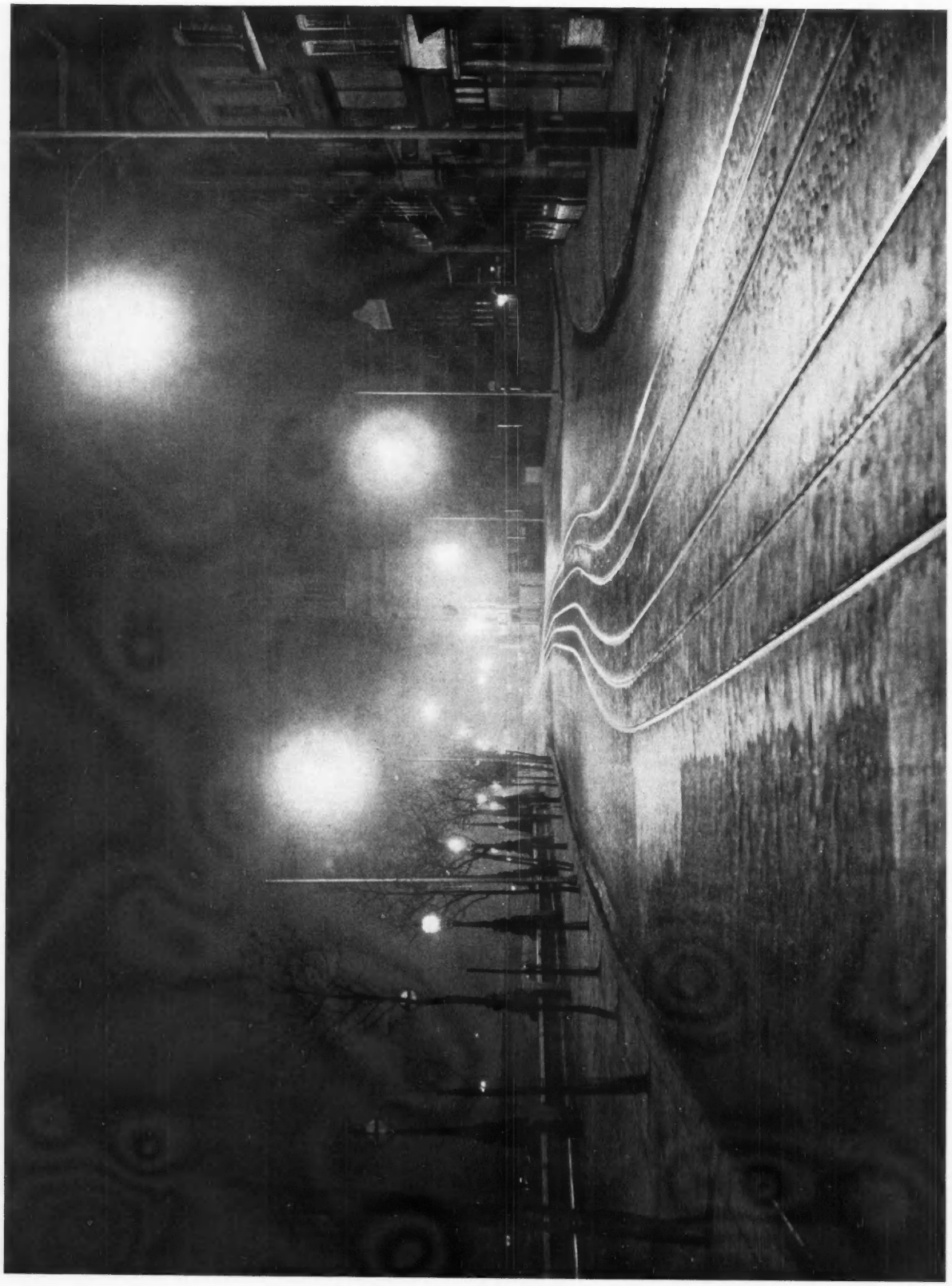
A new dual purpose switch plug comprises a D.P. switch controlling on one side a 15-ampere 2-pin socket outlet, and on the other a 5-ampere 2-pin outlet which is always alive and available for electric both 2-pin and 3-pin patterns. A full range has therefore been designed, consisting of surface, flanged and conduit box types.

A new lampholder for use with architectural striplite lamps embodies a gasket made of specially compounded rubber, moulded to the shape of the lampholder and the contour of the tubular lamp. This renders the unit weatherproof and, moreover, increases its field of utility.

In connection with lighting fittings for the "Queen Mary," approximately 13,000 lampholders of a type patented by the G.E.C. are being supplied.

Finally, it should be recorded that hundreds of thousands of "wedge" type rapid connection lampholders were used during the Jubilee Celebrations.

13. I.E.E. "Regulations for the Electrical Equipment of Buildings," Sept., 1934, p. 15.



"Osira" lighting on the Albert Embankment, London.
Viewing distance, 22 inches.

The Photographic Representation of Street Lighting Installations.*

By R. G. HOPKINSON, B.Sc. (Eng.).,
Research Laboratories of The General Electric Co., Ltd., Wembley, England.

One of the difficulties of the illuminating engineer has always been to record the visibility resulting from a street lighting installation. It is well known that figures alone are inadequate; what is required is a comprehensive visual record.

The investigations described in this article have led to a technique enabling a photographic print to be produced which gives such a qualitative record of engineering value.

INTRODUCTION.

THE increasing reliance placed on visibility as the true criterion of the merits of street lighting installations has given a new significance to street lighting photographs. Photographs to be of engineering value, must be capable of being critically examined, so that the road surface can be carefully inspected, the shape, size, and brightness of the bright patches noted, and the probable visibility in the dangerous dark patches accurately estimated. Such extremely critical judgment is rarely brought to bear on any other type of photograph. It is to be regretted that under this critical judgment, the type of photograph at present being produced is often valueless.

It has been a cause of general comment, voiced by the authors of recent papers on street lighting, that street lighting photographs are quite unreliable as a means of studying the characteristics of an installation. In the absence of any system of representation the photographer has produced in his final print the impression he received of the street during his brief acquaintance with it, or else he has concentrated on the pictorial effect.

There does not appear to be any major technical difficulty which prevents a logical system being formulated. The usual problems of subjective reproduction do not occur. Colour plays little part in the distinguishing of objects at the comparatively low brightnesses encountered in street lighting work, so that little is lost by a monochromatic rendering of an installation.

The object of this work has been to develop a logical system of representation derived from first principles, so that photographs, *i.e.* prints, prepared in accordance with the system will give a qualitative record of the installations they represent, as well as being comparable amongst themselves. Such photographs may not always make the most attractive pictures. A fact which emerged in the course of the investigation was that if a number of prints with different characteristics was made, the print first chosen by memory as most nearly representing the installation was generally brighter and more plucky than the print chosen afterwards under proper viewing conditions in the street. This is because the memory at first tends to flatter the installation. It is only after considerable experience in the judgment of street lighting photographs that an observer realizes that the more pleasant result is not necessarily the more accurate from an engineering point of view. It is necessary to bear this in mind when judging photographs, for it is required to record the installation as seen, and not the installation as recalled.

PHOTOGRAPHIC REPRODUCTION.

For an understanding of the technique to be described, it is desirable that the reasons why a photograph can be a faithful reproduction of a scene should be appreciated. It is well known that photographic representations can be made of a brilliantly lighted snow scene, of a dark interior of a house, or of a dimly lighted street at night, and that each will convey an accurate impression of the original. This range of subjects, with brightnesses varying 100,000 to 1 from the bright snow to the dark street corner, can all be reproduced successfully on the same photographic paper with its limited range of less than 100 to 1. Further, any of the prints can be viewed under a wide range of illuminations varying from low power interior lighting to summer sunlight, with little change in the impression given by the print, although its brightness may be changed a thousand times. Apparently, therefore, the impression conveyed is independent of brightness, whilst at the same time a print which is printed a little too light or too dark is immediately criticised.

There are very good reasons for this apparently

* Paper read on 17th December, 1935 before a joint meeting of the Illuminating Engineering Society and the Royal Photographic Society of Great Britain.

contradictory state of affairs, which is due to the properties of the eye. Although the eye can operate satisfactorily from sunlight to moonlight, the range of brightness that it can perceive at any one moment

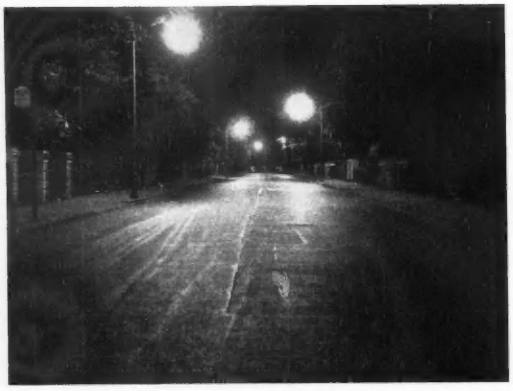


Fig. 1.—A correct representation of a street lighting installation. Viewing distance=4".

Fig. 2.—A print of too great a contrast.

Fig. 3.—A print of too great a density.

is limited. For example, if one is outside a house with an open door, it is usually impossible to distinguish much detail inside the door, because the eye is adapted to the average brightness of the objects outside the house. Those inside are so dark as to be beyond the limiting lower brightness that the eye can detect with that adaptation, although the actual interior may appear to be well lighted to a person inside. Similarly an attempt to resolve detail in the sun meets with complete failure because the brightness of the sun is beyond the upper limiting brightness. Consequently it is not necessary for printing papers to be able to reproduce quantitatively the whole range of brightnesses encountered, but only that they should reproduce in the correct ratio the range of brightnesses that the eye can perceive at a given time. Photographic materials have always fallen short of this ideal, but modern materials carefully handled can portray a range sufficiently great to enable accurate representations to be made, so that not much detail that could be seen by the eye is lost in the print. But as the range portrayed by the paper is not as great as the visual range, some detail must be lost in the shadows and in the highlights. If the same amount is lost in each, a balance is obtained that gives the truest representation possible. But if a slight mistake in printing renders too much detail to be lost in the shadows, relatively to that lost in the highlights, or vice versa, the balance is upset, and the photograph is judged too dark or too light. This explains the second part of the apparent paradox of photographic reproduction.

Street Lighting Photography.

When street lighting photographs are required as a technical record, no artistic licence is permissible in producing them. For example, figs. 1, 2 and 3 are reproductions of three straightforward prints of a lighted street, produced without retouching or "controlled" printing.* Evidently the originals of these figures could not all give the best representation of the subject. There is a difference in contrast between figs. 1 and 2, and a difference in general density between figs. 1 and 3. Contrast and density are under control in the production of a photograph.

Prior to the present investigation it was found possible to produce very fair representations by trial and error methods. The best of these efforts were examined to find if there were any fixed criteria on which they could be judged for the accuracy of their representation. The examination resulted in some definite conclusions on the mechanism by which a photograph is judged. Most certainly it can be judged, and most observers agree in their judgment. It was concluded that for an accurate record the following requirements must be fulfilled :—

First, the photograph must be viewed from such a distance that the subject is seen in correct perspective.

* The half-tone illustrations in this paper are subject to the limitations described on page 60, and do not faithfully reproduce the original prints.

Secondly, the brightness gradation on the print must be the same as in the subject.

Thirdly, the detail visible in the highlights, and also in the shadows, should be strictly comparable with that visible in the subject.

These three requirements form the basis of the method to be described.

While they may not exhaust the problem of correct photographic reproduction, if fulfilled they ensure the production of a photograph satisfactory in every way.

Principles of the Method.

1. *Correct perspective.* The first requirement, correct perspective, is simply that the angle subtended at the eye by an image on the photograph shall be the same as the angle subtended by the original subject. A photograph must therefore be viewed from a distance equal to the focal length of the equivalent lens system[1] by which the photograph was made. At first this point may seem to be trivial. It is in fact of great importance. An erroneous impression of a street can easily be gained by viewing, from the normal viewing distance of 13 inches, a photograph taken with a 4 inch lens. The correctness of the reproduction suffers, the most evident effect being that any dark patches in the corners of the picture will appear large, out of all proportion to their true significance, in the field of view. For general purposes, photographs should be printed so that the focus of the equivalent lens system is about normal reading distance, *i.e.*, about 13 inches, unless they are required for some special purpose; and also when taking the photograph the camera should be set at eye-level, *i.e.*, 5 feet approximately.

There is a small refinement which, although not altering the faithful angular dimensions of the print, can be used to give it a more lifelike character. When a print is viewed at 13 inches the eye is focussed at that distance. When a street is viewed the eye is focussed at, or near, infinity. This infinity eye focus can be obtained by looking through a lens, held close to the eye, whose focal length is the same as the viewing distance of the print. When this is done, no magnification is produced, but the eye operates as it normally would in a street, and conveys an impression of life and solidity to the print not otherwise present.

2. *Correct Contrast.* It is a more formidable problem to reproduce subject brightnesses faithfully, and in the correct ratio. Before treating the subject in detail, the principles of the system which has been evolved can be outlined. In the normal photographic process there are three main controllable factors, exposure of the plate or film in the camera, development of the plate or film, and exposure of the print. It is taken for granted that a fully developed print is always required. The perfect photograph can only be produced by the control of all three factors, with the nature of the final result always in view. In practice it is convenient to standardize two factors and to control the third. For reasons to be explained later development cannot be the variable factor. If printing exposure is to be standardized, plate exposure must be varied. But if any error occurs, a fresh excursion to the installation must be made. If plate exposure be standardized, exposure in printing must be varied. Fortunately errors in printing are more conveniently remedied.

Street lighting photographs can never be taken in conditions which approach comfort, so it is very necessary to make all work done, when photographing the installation, as simple as possible.

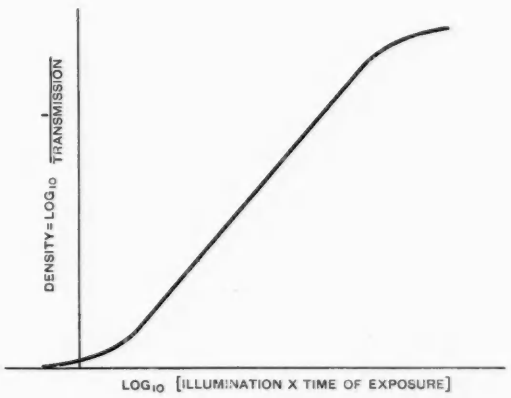


Fig. 4.—Typical plate characteristic.

As the first step in the production of a standardized negative, the exposure to be given to the plate must first be correlated to the range of subject brightness. *Exposure given must always be such that where possible, the whole brightness range of the street surface is reproduced on the negative, and that the proportional representation of brightness is maintained throughout the range.*

Development, which is the second step, controls the contrast of the negative. *Development given must always be such that the subject brightnesses are reproduced on the negative in the correct ratio.*

A negative produced in this way will be a true reversed monochromatic image of the subject. Effectively we have diminished and reversed the street and brought it into the darkroom. We are now at liberty to adjust the printing to produce the true impression conveyed by the street.

The third factor, the printing, must be adjusted so that in combination with the negative, the subject brightnesses[2] can be reproduced in their original

1. The term equivalent lens system implies the focal length of the camera lens for a contact print, and the focal length of the camera lens times the degree of linear enlargement for an enlarged print.

2. The unit of brightness used throughout the paper is the equivalent foot candle, which is defined as the brightness of a perfectly matt white surface of 100 per cent reflection factor, illuminated to one foot candle.

ratios. This can be effected within close limits by suitable choice of printing material and control of developing technique.

3. *Correct density.* The reflection density of the print must now be controlled so that the third condition (page 51) is fulfilled. If the subject brightnesses are reproduced in the correct ratio, the whole photograph can be printed to the correct density if it is possible to calculate the correct density to which one given datum brightness must be printed. The datum density can be determined from a consideration of the physiological characteristics of the eye. The lower limit of brightness, below which, in a given scene, no detail can be perceived, is fixed relatively to the adaptation of the eye at any time. If the adaptation brightness

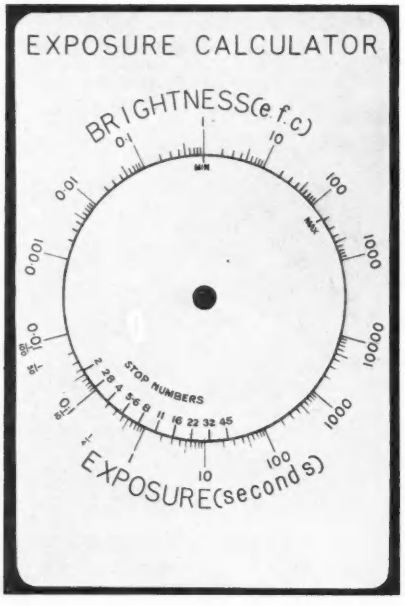


Fig. 5.—Exposure calculator.

of the eye (or the brightness of some part of the subject which bears some relationship to the adaptation brightness) be measured, the lower brightness limit corresponding to the subject can be found. This limiting brightness must then, by the present theory, be represented on the print by a density such that, when viewed under normal conditions, no detail can be seen in it, *i.e.*, its brightness will be at the lower limit corresponding to the adaptation of the eye when viewing the print. Having settled the density to which this brightness should be printed, the scale for other brightnesses follows by direct proportion. Strictly speaking the correct printing density varies with the illumination on the print, for this controls the adaptation brightness and therefore the density for the lower brightness limit. But fortunately the characteristics of the eye are such that, as will be seen later, if the illumination on the print is over about 5 foot candles the correct printing density varies very little. Below this illumination prints appear to be too dark, as they always do when seen by the darkroom light when developing them. If the correct density be found for about 15 foot candles, a print of this density will give a good representation in all illuminations from 5 foot candles to 500 foot candles.

THE TECHNIQUE.

Exposure and Development.

The detailed requirements of exposure and development can best be followed from a consideration of the characteristic curve of the photographic plate or film emulsion.

Fig. 4 shows a typical curve which connects the density of the developed emulsion with the exposure to light. The scale of abscissae represents the logarithm of the product of illumination and time of exposure, and the scale of ordinates, the image density or the logarithm of $\frac{1}{\text{transmission.}}$ Such a curve is usually straight throughout the greater part of its length. This means that between the abscissae of the points at either end of the straight line portion, the image density is a constant proportion of the logarithm of the product of illumination and time of exposure. If a given difference in incident light produces a proportional difference in the transmission of the plate, the slope of the line will be unity. Hence a negative of unity slope is a true reversed image of the subject. This type of negative is desirable for our purpose, and the factors that determine the slope must be carefully investigated.

Exposure.

This characteristic curve of a photographic emulsion can also be applied to connect image density and subject brightness. If the plate or film be exposed in the camera to a subject, the illumination at any point on the plate is directly proportional to the brightness of the subject at the corresponding point and depends on the light transmission of the lens system and aperture. Since there is a direct relationship between subject brightness and the illumination on the plate, the characteristic curve will give the connection between image density and subject brightness. The characteristic is more conveniently used in this form. It shows the range of subject brightness that can be included on the straight line portion of the characteristic for a given time of exposure at a given stop. Conversely, if the brightness range of the subject be measured, a suitable time of exposure can be calculated for a given stop, to include this range on the straight portion of the characteristic curve, provided it is true to say that the same value of the product of

illumination (and therefore brightness) and time of exposure always produces the same image density irrespective of the separate values of the factors.[3] Many workers have investigated the truth of this assumption, and their work demonstrates that for fast plates the error incurred in making it when dealing with the range of brightness encountered in street lighting work is not serious. The experience of the writer confirms their findings.

The calculation of the time of exposure is quite simple in the comfort of the laboratory, but when working on a cold night in the middle of a street, errors are very liable to occur. A calculator has therefore been designed to perform the arithmetical part in determining exposure. A fixed dial carries scales of brightness and exposure, whilst on the moving dial are marks indicating the brightness range of the particular emulsion used, and other marks indicating lens apertures. The range of any other emulsion can of course be engraved on the dial. In use, the brightness range of the street, having been measured, is found on the brightness scale and straddled by the plate marks. The correct exposure is then found opposite the appropriate lens aperture. (Fig. 5 shows the calculator adjusted as it would be for a brightness range of, for example, 2 e.f.c. to 20 e.f.c., indicating an exposure of 6 seconds at f.22. In appendix 3 data are given for the construction of an exposure calculator for use in pictorial photography.)[4]

The measurement of the maximum and minimum brightness of the subject can conveniently be measured with an instrument recently designed by J. M. Waldram for work on street lighting installations, a description of which is given in appendix 1.

An exposure meter which does not actually measure the brightness range is not suitable for street lighting photography. Photo-electric exposure meters are therefore not desirable. The exposure indicated by such a meter cannot be correct, because it does not ensure that the brightness range is rendered on the straight portion of the curve, but simply integrates the whole range of brightnesses, including that of the sources, and indicates a mean exposure. In any event, a photo-electric meter is not reliable because readings given at low brightnesses are not very accurate.

No allowance has been made in the calculator for the variation of plate sensitivity with the wavelength of the incident light. In the course of work over the past year, a very great number of photographs for photometric measurements have been taken on panchromatic plates with illuminants of different colours, and the densitometer records obtained from these plates have shown that no modification in exposure is required. It has not been considered necessary to examine, with any greater exactitude, the colour response of the materials used.

The wavelength of the incident light has some slight effect on the slope of the characteristic,[5] that is, that with the same after-treatment, a negative

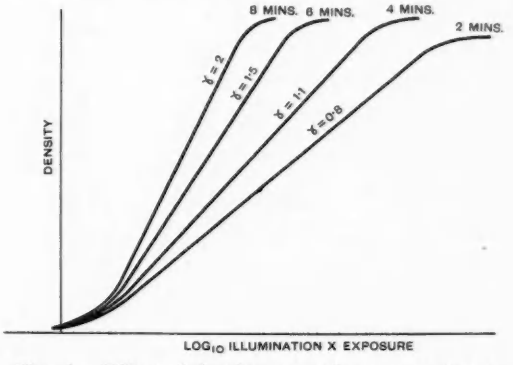


Fig. 6.—Effect of development time on contrast.

exposed to light of longer wavelength will be more contrasty than one exposed to light of shorter wavelength. A brief investigation into the effect has been made and is recorded in appendix 4, where it is shown that the effect is so small that it is doubtful if the representation is materially improved by making compensation for it.

Development.

The development given to a plate controls both the density and the contrast of the image. Increased development increases both density and contrast. Consequently if a definite contrast is required, the development given must be standardized, and the density of the image cannot therefore be controlled by development (see page 51). The most satisfactory method of development for street lighting photography is the time and temperature method, and it

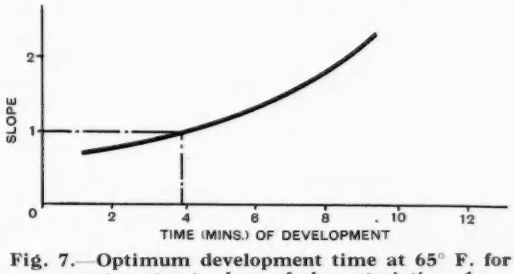


Fig. 7.—Optimum development time at 65° F. for correct contrast, slope of characteristic = 1.

is convenient to develop for a fixed time at a fixed temperature. If this is not always practicable, a time and temperature table must be used. It is advisable for the photographer to draw up his own table for the developer and apparatus he uses.[6]

3. F. Ross, Journal of Optical Society of America, 1920.

4. See also Dow & Mackinney, "Illuminating Engineer," 1911, for an interesting article on exposure.

5. Dobson, Griffith & Harrison, "Photographic Photometry," (Oxford 1926).

6. A method is given in the "Dictionary of Photography" (Iliffe) See appendix 2.

Some notes on development are given in appendix 2, which should be consulted.

The effect of time of development on the slope[7] of the characteristic of the emulsion is shown in fig. 6. The slope of the characteristic determines the relation between the image density and the illumination, that is to say, the slope is a measure of the contrast of the negative, as has been shown previously. If the required contrast has been predetermined, the correct time to develop to give that contrast must be found by plotting slope of characteristic (*i.e.*, contrast) against time of development (see fig. 7) and from the resulting curve the required time found. For the system of representation under discussion it is convenient, but not necessary, for the slope to be unity, hence from the curve (fig. 7) we can find the correct time of development.

If the equipment necessary for determining this time is not available, the manufacturers of the emulsion used should be consulted.

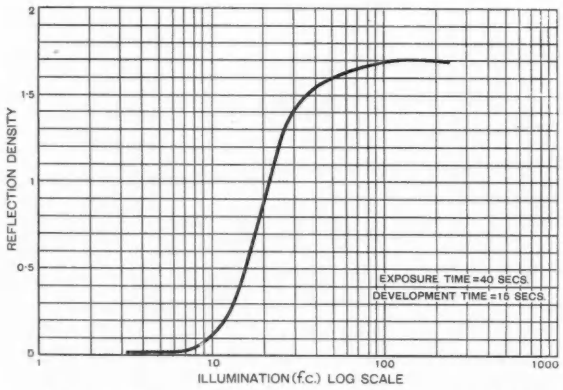


Fig. 8.—Characteristic of extra vigorous gaslight paper.

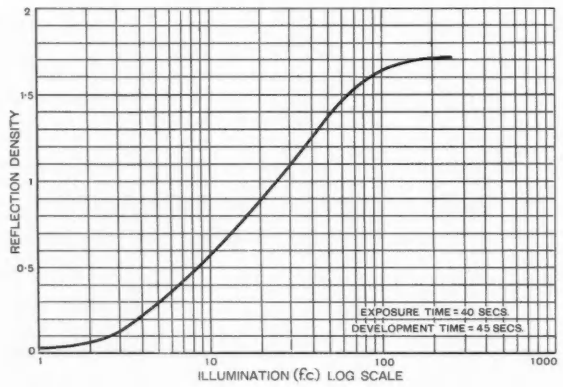


Fig. 10.—Characteristic of extra soft gaslight paper.

7. The straight line portion of the characteristic can be expressed by an equation of the form :— $D = \gamma \log It + i$
where D = density.
I = illumination.
t = time of exposure.
i and γ are constants.
γ is the slope of the line.

Choice of Material for Producing the Negative.

It follows from the considerations outlined, and from convenience in working, that the chief points to bear in mind when choosing material are as follows :—

1. Speed. As fast an emulsion as is practicable from other considerations is desirable for street lighting work to keep the exposures as short as possible.
2. Freedom from liability to chemical fog.
3. Considerable latitude.
4. As uniform sensitivity as possible to all visible radiation.
5. Absence of objectionable grain.

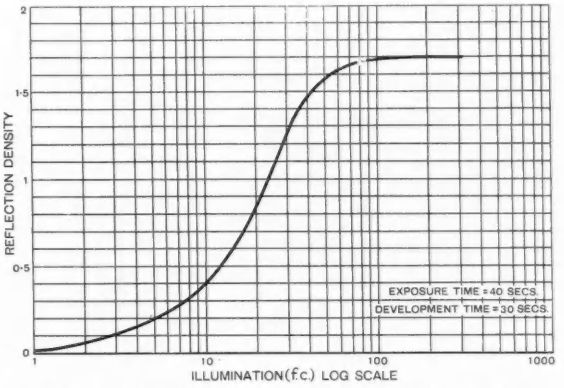


Fig. 9.—Characteristic of medium gaslight paper.

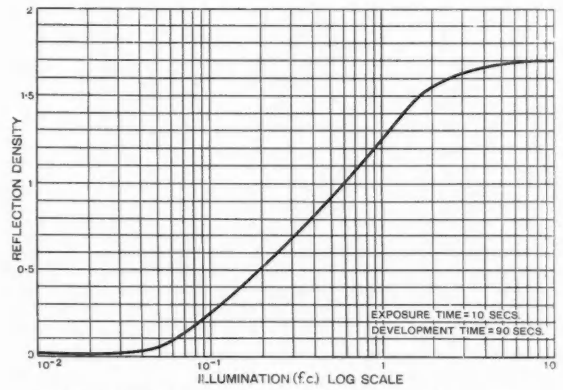


Fig. 11.—Characteristic of soft bromide paper.

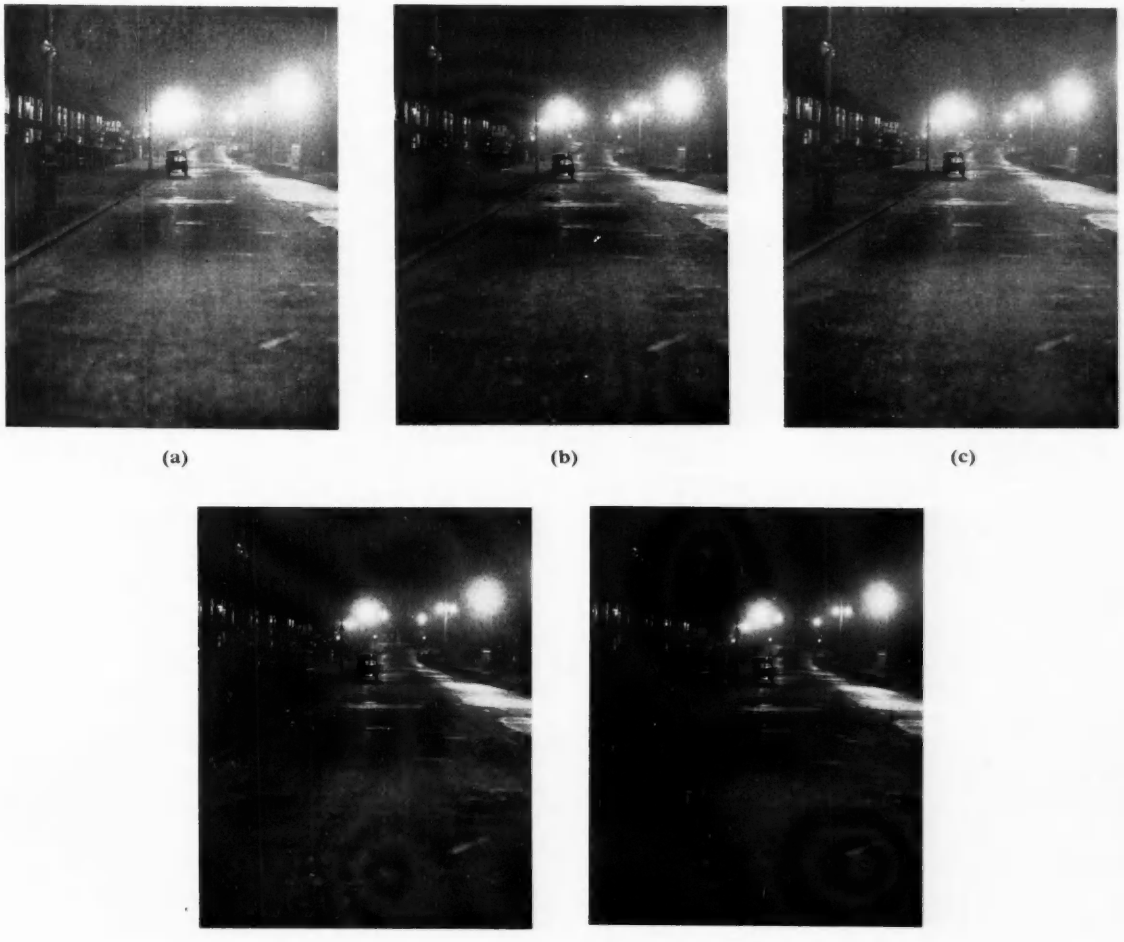
Usually the faster an emulsion the greater the liability to chemical fog, so that an optimum speed depending on the tolerable fog must be found. Fast emulsions are usually of soft gradation, which is desirable. Fast emulsions also tend to graininess, but by using a fine-grain developer and generally studying development, both chemical fog and graininess can be greatly diminished. Films or backed plates must always be used in street lighting work. If the emulsion has substantially the same sensitivity to all colours of the spectrum, no

modification of the calculated exposure will be necessary when taking photographs of installations lighted by discharge lamps emitting coloured light. Hence it is essential to use a good panchromatic material.

There is now commercially available a good selection of fast panchromatic plates and films which combine the desirable properties enumerated above to a greater or lesser degree. It is recommended that a suitable material should be chosen, and always used.

of the transmission, but as a function of print paper reflectivity.

The characteristics of some printing papers are shown in figs. 8, 9, 10 and 11. The curves connect the logarithm of the exposure with the corresponding reflection density, *i.e.*, the logarithm of the reciprocal of the reflection factor of the paper, taking the base as unity. A type of paper with a straight line portion to its characteristic is necessary, as otherwise the gradation of the negative will not be correctly



(a) (b) (c)

(d) (e)

Fig. 12.—Prints of graded density.

Printing.

A negative produced on the lines indicated should be a perfect reversed image of the subject. This negative must now be re-photographed to produce a positive image on paper.

The same considerations which governed the production of the negative hold in the production of the print. The printing paper emulsion has a characteristic similar to that of the plate, but it is necessary to define the image density not as a function

reproduced on the print. The extra soft gaslight paper and the soft bromide paper whose characteristics are reproduced in figs. 10 and 11, were examined and found to fulfil this requirement, for when fully developed both papers will give characteristics whose slope is unity. Hence, by printing or enlarging on these papers in the way specified, the subject brightnesses can be reproduced in the correct ratio on the prints, and the second main requirement for correct representation will have been obtained.

Correlation between Paper Density and Subject Brightness.

Actual brightness cannot be spoken of numerically when discussing prints, for it depends on the illumination on the print and on the density of the print image. The former is variable, but the latter is a property of the print that can be specified. Hence a correlation between print paper density and brightness of the road surface is required. This correlation has been determined both experimentally and theoretically.

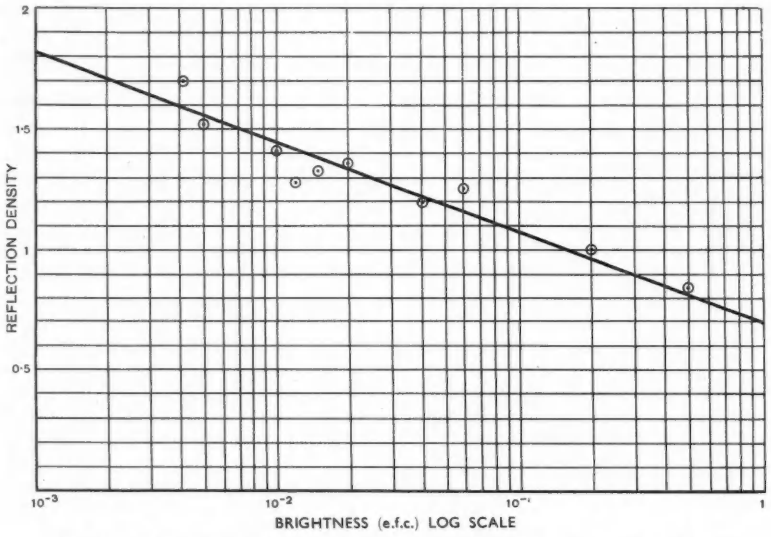


Fig. 13.—Experimental relation between paper density and minimum brightness of road surface.

Experimental Correlation.

Ten representative installations were examined and photographs taken of each. The negatives were exposed and developed according to the principles outlined previously. From each of the ten negatives five prints were made, each rendering the contrast the same as on the street, but the five prints were of different overall density (see fig. 12). Expert observers who knew the installations well, were asked to pick out which of the five prints most nearly gave them the impression conveyed by the installation. This choice was made when comparing the installation with the prints from the same view point as that from which the photograph was taken. The prints were judged by the loss of detail in the dark parts due to over-printing, by the gain of detail in the dark parts and the loss in the highlights due to under-printing, and by the general impression given by the prints. The most accurate prints were chosen and in the laboratory the print paper density of the areas of minimum brightness was measured. A curve was then plotted connecting these densities and the brightnesses they represented. The resulting relation was a straight line, as shown in fig. 13, whose slope was calculated and shown to be 0.35.

Further photographs of different installations were made using this scale, and in every case a true representation was obtained which withstood the most critical inspection.

These results suggested that the correlation had some fundamental basis. An investigation was made, therefore, to find this basis, and this investigation followed the principles which have been outlined in the introductory part of the paper.

THEORETICAL DEDUCTIONS.

The relation which has been mentioned in the introductory part of the paper, between the background brightness level to which the eye is adapted and the corresponding lower limit of brightness visible, has been investigated by many observers, and a summary of their results is given in the curve shown in fig. 14[8]. This relation when plotted on logarithmic co-ordinates, is represented by a straight line over the range encountered in street lighting work.

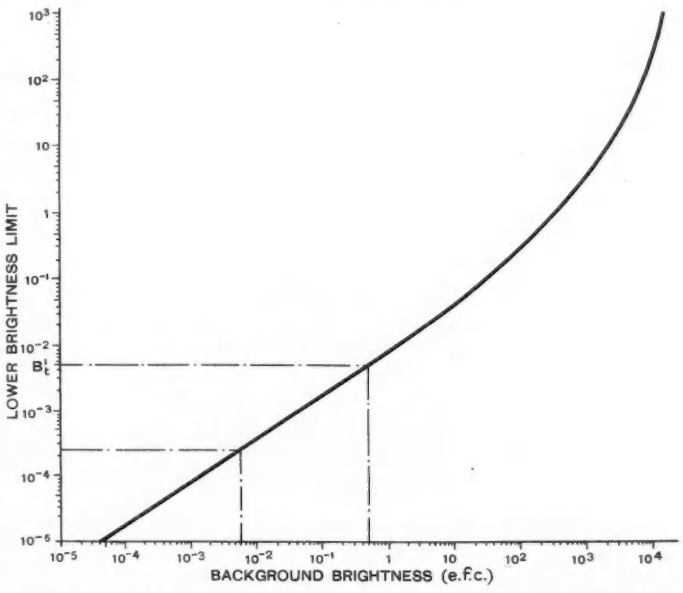


Fig. 14.—Variation of lower brightness limit with background brightness (after Nutting, J. Opt. Soc. Am. 1920).

When a subject is viewed, the eye is adapted to a level of brightness which will be called the

8. Ref. U. Bordoni, "L'Elettrotecnica." Vol. XI., Sept., 1924. Nutting. J. Opp. Soc. America, 1920.

equivalent background brightness, B_{eq}. For a given value of background brightness (B'_{eq}) the corresponding lower brightness limit will be B'_t as found from fig. 14. In an accurate representation photograph a brightness of B'_t should be represented by an area on the print of density such that when viewed under a given illumination, this area has a brightness equal to the lower limit corresponding to the eye adaptation level when looking at the print. The calculation of the numerical value of this density will be left until later. For the moment it will be called D_o.

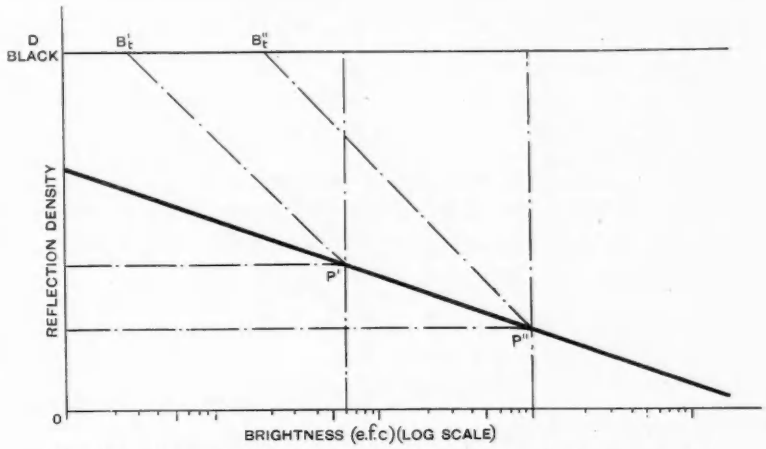


Fig. 16.—General relationship between paper density and equivalent background brightness.

Now consider a hypothetical photographic process which is capable of producing a positive print, on which the whole range of brightness which the eye can resolve at one level of adaptation can be represented in the same ratio as on the subject. The relation between subject brightness and the density of such a print can be represented on logarithmic scales by a straight line of unity slope (fig. 15). From the assumption that a brightness of B'_t must be represented by D_o, we know that one point on this line is (B'_t, D_o), and hence the line is completely defined for any one value of B_{eq}. The density which should represent any other brightness can be obtained from this line, which we will call the print characteristic. For any other values of B_{eq} other print characteristics can be found which will be parallel straight lines of unity slope. From all of these lines can be determined the density corresponding to the value of B_{eq} for which they were drawn. In fig. 16 two such lines B'_t P', B_t'' P'' have been drawn, and two points P' (B'_{eq} D'_{eq}) and P'' (B''_{eq} D''_{eq}) obtained, giving the density at which the equivalent brightness should be printed. The locus of such points is a straight line correlating print density and the equivalent background to which the eye is adapted. The slope of this straight line is 0.34.

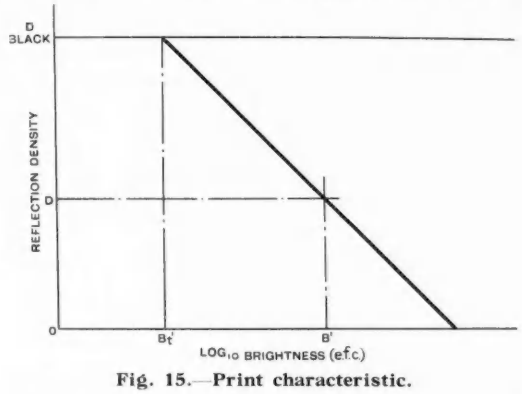


Fig. 15.—Print characteristic.

When an observer is viewing an artificially lighted street surface, his eye is adapted to an equivalent background brightness which is a function of the various brightness values occurring in his field of view. Owing to the fact that there is rarely a large area of the street surface whose brightness is the same as the equivalent background brightness, the relation which we have obtained in fig. 16 cannot conveniently be used. We must therefore find a datum area on the street surface which is sufficiently large on the print for its density to be conveniently measured. The brightness of this datum area must be measured, and the density by which to represent it on the print found from the print characteristic

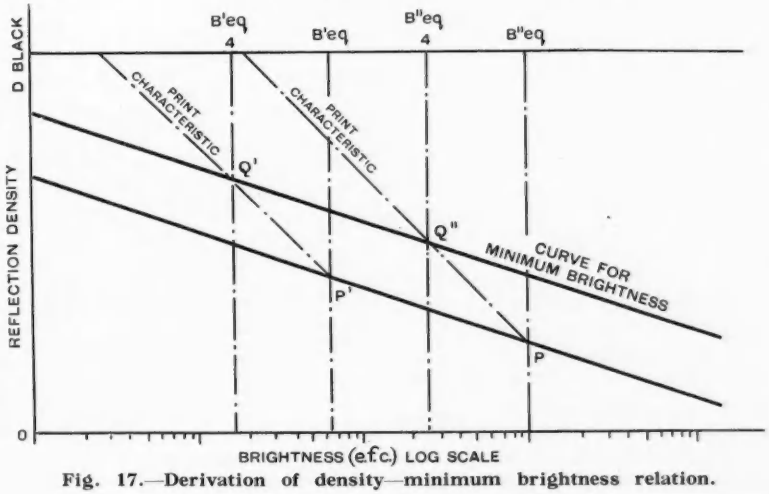


Fig. 17.—Derivation of density—minimum brightness relation.

corresponding to the equivalent background of the installation. The area of minimum brightness on a street surface is usually large and conveniently situated for such measurement, as can be seen from fig. 23. The remarkable agreement between the slope of the relation between density and equivalent background brightness theoretically deduced, and the slope of the relation between density and minimum brightness experimentally deduced, suggested that some constant factor might connect the equivalent background and the minimum brightness of a street lighting installation. Measurements were therefore made on a number of installations, and it was found that there was evidence for the existence of such a constant factor. The average value of this factor for the installations examined was one-fourth. If this factor of one-fourth be used, a theoretical relation can be obtained connecting minimum brightness and the density of that part of the print representing the area of minimum brightness. This relation has been derived in fig. 17 in the following way. P' P'' is the same line as in fig. 16. The points P' and P'' correspond to equivalent backgrounds of B'_{eq} and B''_{eq}. The minimum brightness of a road surface whose equivalent background brightness is B'_{eq} is $\frac{B'_{eq}}{4}$, so the density by which to represent this brightness can be found from intersection of a perpendicular from $\frac{B'_{eq}}{4}$ with the print characteristic, giving a point Q'. Similarly for $\frac{B''_{eq}}{4}$ a point Q'' is obtained. The locus of such points is a straight line parallel to the previous line.

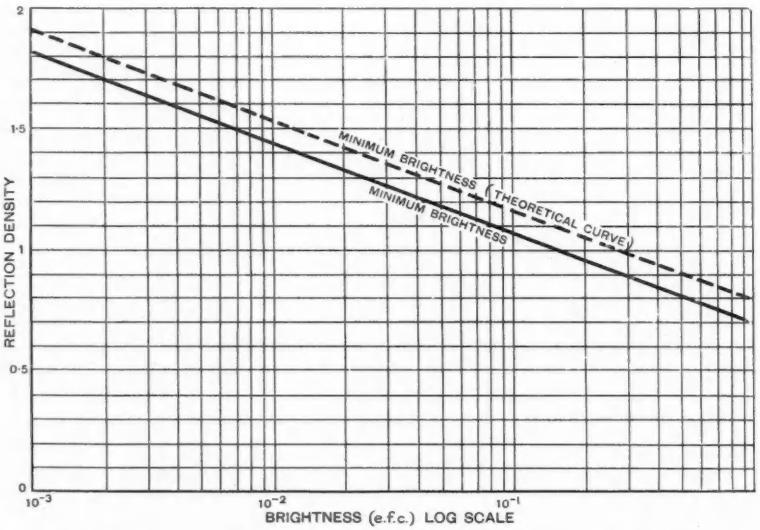


Fig. 18.—Experimental and theoretical curves connecting minimum brightness with reflection density.

The actual numerical agreement of the theoretical and experimental results will depend on the value which is taken for the print density to represent the limiting brightness. When the sets of prints (fig. 11) were examined, they were all illuminated to 16 foot candles, so that the eye would, in all probability, have been adapted to a brightness of 8 e.f.c. because the average reflection factor of the objects in the field of view was 50 per cent. The lower brightness limit corresponding to 8 e.f.c. is found from fig. 14 to be .034 e.f.c., which would be the brightness of an area of the print having a density of 2.55. Hence

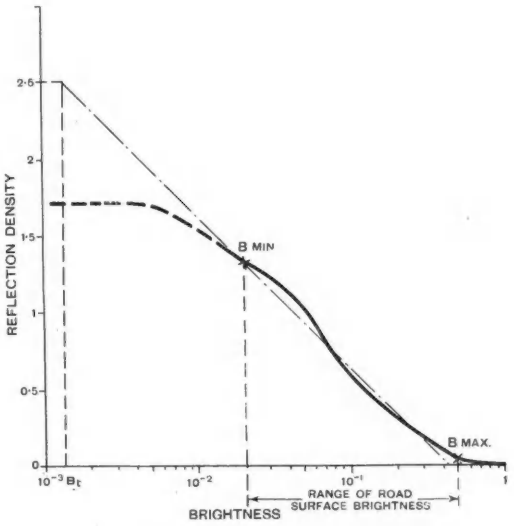


Fig. 19.—Actual print characteristic.

this value of density would appear quite black if a print were viewed under 16 f.c. With this value of density as datum, scales can be inserted on figs. 15, 16 and 17.

Fig. 18 (which is fig. 17 re-drawn with appropriate scales), gives the theoretically deduced curve connecting minimum brightness with reflection density (shown in dotted lines). The experimentally deduced curve has also been reproduced on fig. 18, and the agreement between the experimental and theoretical curves is seen to be good. In practice the ratio of the equivalent background brightness to the minimum brightness, although of the order of 4, will vary slightly according to the type of installation. It will be seen, however, that a variation of this ratio over quite wide limits will not materially alter the impression conveyed by the photograph if the average value of 4 is taken. Consequently the full curve of fig. 18 can be used as the working correlation for the production of prints.

Although the photographic materials used cannot

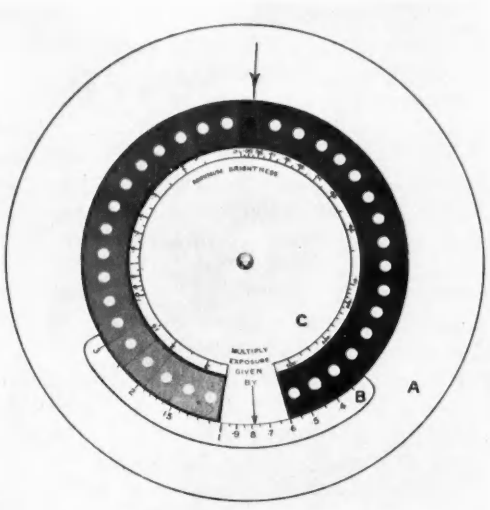


Fig. 20.—Print exposure-density calculator.

reproduce the complete range of brightnesses perceived by the eye at a given adaptation level, and particularly as low a density as 2.55, the representation given is far more accurate than might at first be supposed. Fig. 19 shows the actual overall characteristic of a street lighting photograph, which has been obtained by plotting subject brightness against print density. The street surface brightnesses are seen to be represented in the correct ratio, so that the greater part of the photograph is as it should be, but brightnesses which are much below the minimum street surface brightness are represented by too low a density, because of the failure of the print paper to give a density above 1.7. This does not greatly detract from the value of the photograph for the following reasons. The absolute lower limit as given by Nutting is a laboratory figure. In general, although detail is visible down to this lower brightness limit, it becomes vague at about ten times that limit, so that even if detail could be portrayed by the printing paper down to the limit, little gain in the perfection of the representation would be obtained. Although this detail would be represented on the print it would be vague, as it was on the street, because of this characteristic of the eye. The effect would therefore be almost the same as is now obtained with ordinary materials.

Due also to the limited range of the paper, it is quite impossible to render correctly the brightness of the sources, and thus to show any effect they may have on the appearance of the installation. Here again it has been found that the truth of the representation is not affected in any important degree. If, for any particular purpose, it is desired to obtain an impression of the effect of the source brightnesses, the photograph can be viewed in the following way. The print is backed with black paper and holes of the appropriate size are punched through the images of the sources. The photograph is placed above a background of such a brightness that the sources are of the correct intensity relatively to the brightness of the print. When viewed through a lens of the appropriate focal length, as perfect a photographic representation of an installation as can be expected will be obtained.

PRODUCTION OF PRINTS AND SLIDES.

Production of Prints.

In order to facilitate the use of the standard density scale of fig. 13 when producing prints, a print exposure-density calculator has been constructed. This, as shown in fig. 20, comprises a fixed base A, with a small hole indicated by an arrow, a moving dial C consisting of a large number of graded density steps with a brightness scale corresponding to the curve of fig. 13, and finally an exposure dial B. The brightness scale on C is set so that the value of the minimum street surface brightness is opposite the arrow on A. The exposure dial B is moved so that the arrow on dial C is opposite 1 on B. A and B are then fixed relatively to one another. The meter is laid over the datum area of minimum brightness on a trial print made on the correct grade of paper, and the dial C is moved about until one of the graded steps is found which has the same density as the datum area. Then the figure on B opposite the arrow on C indicates the factor by which the exposure given to the trial print should be modified to give the final print.

Production of Lantern Slides.

The standard density scale can be directly applied to the production of lantern slides. A lantern slide emulsion which gives the correct contrast is of course used. The transmission density of the slide must be same as the reflection density of a print in corresponding parts.

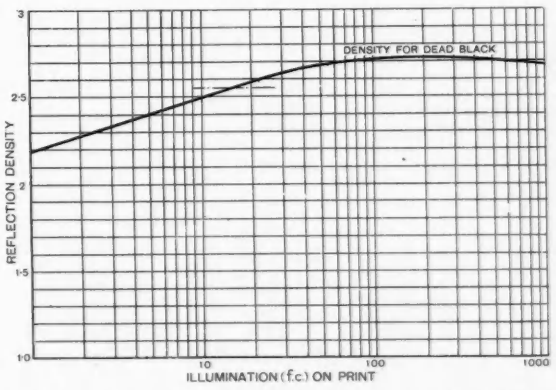


Fig. 21.—Relationship between reflection density and illumination on print.

The density of the slide is best measured by a suitable type of densitometer. It is also possible to make reasonably accurate determinations with the print density calculator already described. The lantern slide should be held above a white surface whose reflection density is 0, and the calculator placed over the datum area so that it receives the same illumination as the white surface. For a correctly printed lantern plate, the datum area should appear of the same brightness as the step of the calculator whose density corresponds to the datum brightness in the street.

Lantern slides can only give true representations when projected by a beam of sufficient intensity to provide adequate illumination on the screen. The screen illumination when no slide is in the lantern should not be less than 6 foot candles.

Stray light may completely spoil the effect. Correct perspective is difficult to obtain with projection, and it should be fully realised that in practically every case a projected lantern slide subtends only a fraction of the correct angle at the eye.

ILLUMINATION ON PRINTS PRODUCED IN CONFORMITY WITH THE STANDARD DENSITY SCALE.

The reason why a standard print will give good representation over a wide range of illuminations, can be deduced from fig. 14. This curve, which connects the lower limit of brightness visible with the background brightness, can be replotted as a connection between the upper limit of density which will appear quite black, and the illumination on a print. This has been done to give fig. 21, where an average reflection factor of the field of view of 50 per cent has been assumed.

It will be seen that this density is reasonably constant between 5 and 1,000 foot candles, and the value taken when drawing fig. 18, $D_o = 2.55$ at 16 foot candles, is seen to be an average value.

PHOTOGRAPHS FOR REPRODUCTION.

A short investigation was made to find whether the faithfulness of reproduction was affected by reproduction by photo-mechanical processes.

Half-tone Reproduction.

The curves (fig. 22) show the effects produced by half-tone reproduction. The upper curve is the relation between reflection density and illumination on the paper for a soft bromide paper. The curve was obtained by printing through a calibrated step-tablet divided into twenty strips, and measuring the density of each strip of the resulting print. A half-tone block was then made of the print, and pulls taken on art surfaced paper and on good quality newsprint. The reflection densities of the corresponding steps were measured, and from these the lower two curves were drawn. The curves show that although the contrast is not greatly altered by the half-tone process, the range of density is shortened considerably. The shortening of the range of density is caused first by some ink always printing out in the high lights, although the primary print is white in those areas, and hence the density of the white parts is 0.08 against 0.0 on bromide paper, and secondly good blacks are not obtainable, the highest density on journal paper being 1.1 against 1.7 on bromide paper. The half tone reproduction can, therefore, record faithfully a brightness range of only 10–1 against 50–1 on gaslight and bromide paper. The contrast is there-

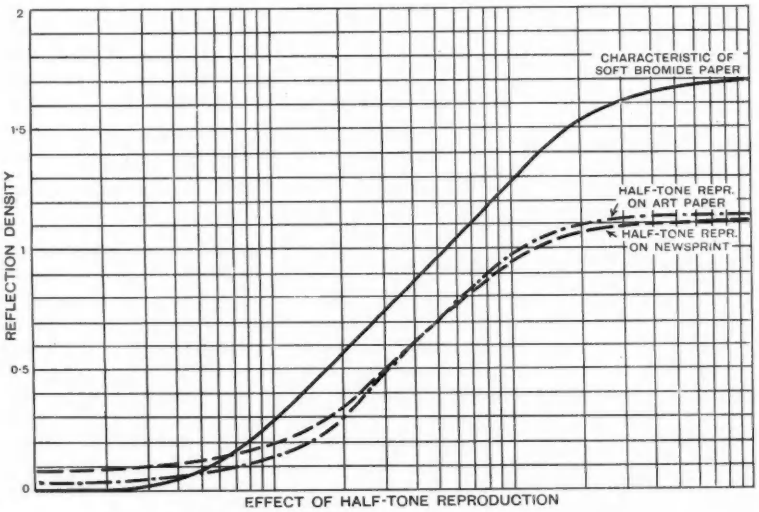


Fig. 22.—Effect of half-tone reproduction.

fore destroyed over part of the range, the highlights and the shadows clogging up. Over the middle of the range the contrast is nearly the same as on the primary print.

Fuller investigation has not been possible, but it is evident that half-tone printing as commonly produced is less faithful than the photographic print. The half-tone illustrations in this paper are subject to the limitations described above.

Photogravure.

A similar investigation of the photogravure process was not possible, but an examination of a number of high quality photogravure reproductions showed that this process may have some advantages over the half-tone process. Densities of from 0.1 to 1.8 were produced in the illustrations but the reproduction of contrast could not be determined.

SUMMARY OF PROCEDURE INVOLVED IN THE TECHNIQUE.

The foregoing procedure can be summarized in the following eight steps.

1. Set camera at average eye-level (5 ft.).
2. Measure maximum and minimum brightness of the road surface. Note carefully, preferably on a sketch, where the area of minimum brightness occurs.
3. Set the exposure calculator to straddle the brightness range of the street, and read off the correct exposure for the stop used.
4. Develop for the time which gives correct contrast with the developer and method of development used.
5. Arrange, by enlarging if necessary, that the focal length of the equivalent lens system of the final print is the same as the distance from which the print is to be viewed.
6. Use soft bromide paper or extra soft gaslight paper in order to obtain correct contrast.
7. Set the measured minimum brightness to the arrow on the fixed base of the exposure-density calculator. Set the exposure scale on 1.
8. Make a trial print, noting the time of exposure and developing fully. Place the calculator over the area of minimum brightness on the print and find the modification necessary to the exposure. Using this modification make the final print.

* * *

The technique of the photographic representation of street lighting installations has been fully described. The illustration on page 48 shows a half-tone reproduction from a photograph produced by this technique. It shows, within the limitations of the half-tone reproduction of the original print, that photography, far from being as hitherto, an unreliable guide to the illuminating engineer, can be one of his most valuable aids.

In conclusion, the author wishes to acknowledge the help rendered by the Research Laboratories of Messrs. Kodak Limited, by the Ilford Research Laboratories, and by Mr. J. S. Dow, in the conduct of the investigation.

APPENDIX I.

Measurement of Brightness.

Fig. 23 shows a photograph of a street, the crosses marking the positions of maximum and minimum brightness of the street surface. The brightness meter as can be seen from the photograph (fig. 25), consists essentially of 15 silvered spots in a field of clear glass placed at 45° to a translucent screen illuminated from one end. These 15 spots will therefore be of brightness decreasing from the brighter end of the screen. The street is viewed through the glass field and the meter moved about until one of the spots disappears, or nearly disappears, against the background of the part of the street whose brightness is required. The meter is calibrated to read equivalent foot candles (e.f.c.). The two photographs, figs. 24(a) and 24(b), show the meter measuring the maximum and minimum brightness of the street shown in fig. 23.

The position of the datum area of minimum brightness can be seen in the photograph (fig. 23). It usually occurs quite near the camera, at the side of the street as shown.

Fig. 23.—Positions of max. and min. brightness on a street surface. The area of min. brightness is usually large and in the foreground of the photograph.

APPENDIX II.

Investigation of Development.

The manufacturers of photographic materials are usually willing to provide information about optimum development time. If there is apparatus available, it is both preferable and instructive to investigate the characteristics of the developer and method used.

Fig. 24 (a).—Brightness meter reading maximum brightness on a street surface.

Fig. 24 (b).—Brightness meter reading minimum brightness on a street surface.

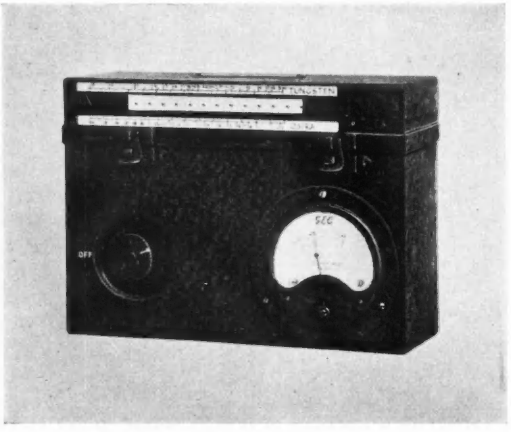


Fig. 25.—Brightness meter.

Four plates or films are given the same exposure behind a calibrated stepped optical wedge under a known illumination. The four plates or films are developed for different times, at the same temperature and by the same process. The characteristic of each emulsion is next obtained. Care must be taken when measuring density, for the scatter will render the measured density much greater when parallel incident light is used and direct transmission measurement, than when a method of diffuse incident light is employed. It is recommended that the method of diffuse incident light be used to measure the density, and that the same type of lighting be used for printing and enlarging.

A series of curves, as shown in fig. 6, will be obtained. The desired time is that which produces unity slope of characteristic, and can be found by plotting slope against time of development (fig. 7).

One variable is avoided if the plates or films are always developed for the same time at the same temperature, but where this is not possible, a time-temperature table must be employed. The Dictionary of Photography (Iliffe), under the heading "Development," describes a simple method for determining a time temperature table for a developer. The method need not be repeated here; it will, of course, be realised that the description there refers to dish development, and that certain modifications will be necessary according to the method used by the investigator.

If the negative is to be enlarged, a fine-grain developer is, of course, desirable. Otherwise a standard developer recommended by the manufacturer for the plate being used should be suitable. If very fast plates are used, more care is needed in the choice of developer because of the greater liability to chemical fog and graininess. This is a matter for experience to decide. Generally it has been found that less fog is produced if a strong developer acts for a short time, than if development is prolonged and a weak developer used.

It is worth while taking precautions to obtain evenly developed negatives. It is always desirable

to keep the developer continuously moving over the surface of the plate. This is effectively done, as suggested by Dr. W. Clark, by brushing the plate surface with a soft wide camel hair brush. A deep dish, larger than the plate, should be used, and plenty of developer is preferable.

The method of development alters the time for correct development at a given temperature, and hence the photographer must draw up his own temperature-time table, unless he uses exactly the same procedure as the publisher of the time table he wishes to use. Dr. Dobson has suggested to the writer that the time of development is affected by two considerations, first the time for fresh developer to diffuse through the stale developer in the emulsion, this time not being affected by temperature, and secondly the time occupied in actual chemical reaction, which is affected by temperature. If the first time is decreased by forcing the stale developer away from the emulsion, the effect of temperature on the time will be greatly increased.

APPENDIX III.

Construction of Exposure Calculator.

The fixed dial of the calculator has two similar logarithmic scales, one of brightness in equivalent foot candles, and one of exposure time in seconds, at opposite sides of the dial. The moving dial has stop marks engraved on one part of its circumference. The relative exposures necessary to give the same results with these stops determines their distance apart. Thus the exposure for f.11 is half that required for f.16, so that the distance apart of these marks is that which represents x2 on the logarithmic scale used for exposure.

The following considerations apply when marking the range of a plate or film emulsion on the calculator. A brightness of 1 e.f.c. when photographed through a lens of 100 per cent transmission whose aperture is f.11, produces an illumination on the emulsion of 0.0065 foot candles. The average transmission of most lenses is of the order of 60 per cent, so that the effective conversion factor is 0.004. The straight line range of the emulsion, measured in foot candle seconds, should be obtained from the manufacturers of the plate or film to be used. Suppose this range is from 0.002 f.c.s. to 0.2 f.c.s. Dividing these values by 0.004, the conversion factor for f.11, the brightness range at f.11 is seen to be from 0.5 e.f.c. seconds to 50 e.f.c. seconds. Setting the calculator so that the f.11 mark is opposite the 1 second mark, the range of the plate can be marked in from the brightness scale, the minimum mark being made opposite 0.5 e.f.c. and the maximum mark opposite 50 e.f.c.

Fig. 26 shows a scale marked in degrees of arc which can be substituted for the plate marks. When the calculator is set for f.11 to be opposite 1 second, the zero of the scale is on 0.001 e.f.c. The range of various emulsions can now be expressed in terms of these degrees, preferably in the form of a table to be used in conjunction with the calculator.

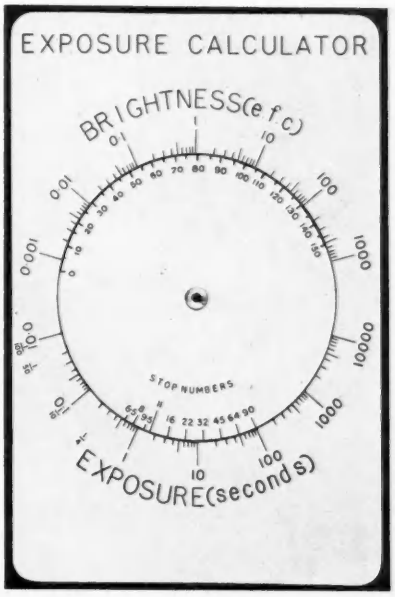


Fig. 26.—Exposure calculator with degree scale. The straight line range of an emulsion can be expressed on the degree scale.

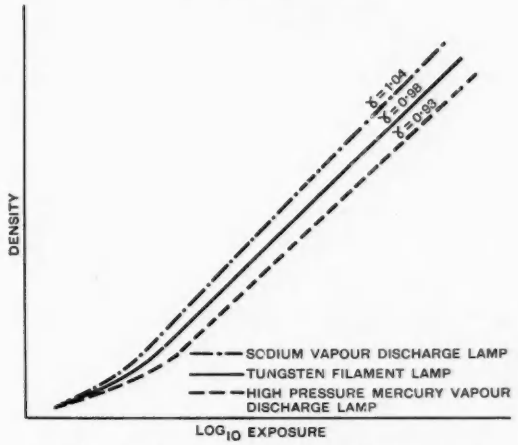


Fig. 27.—Effect of colour of light source on characteristic of panchromatic plate.

Such data could be supplied by the plate or film manufacturers.

APPENDIX IV.

Effect of Colour of Light Source on Contrast.

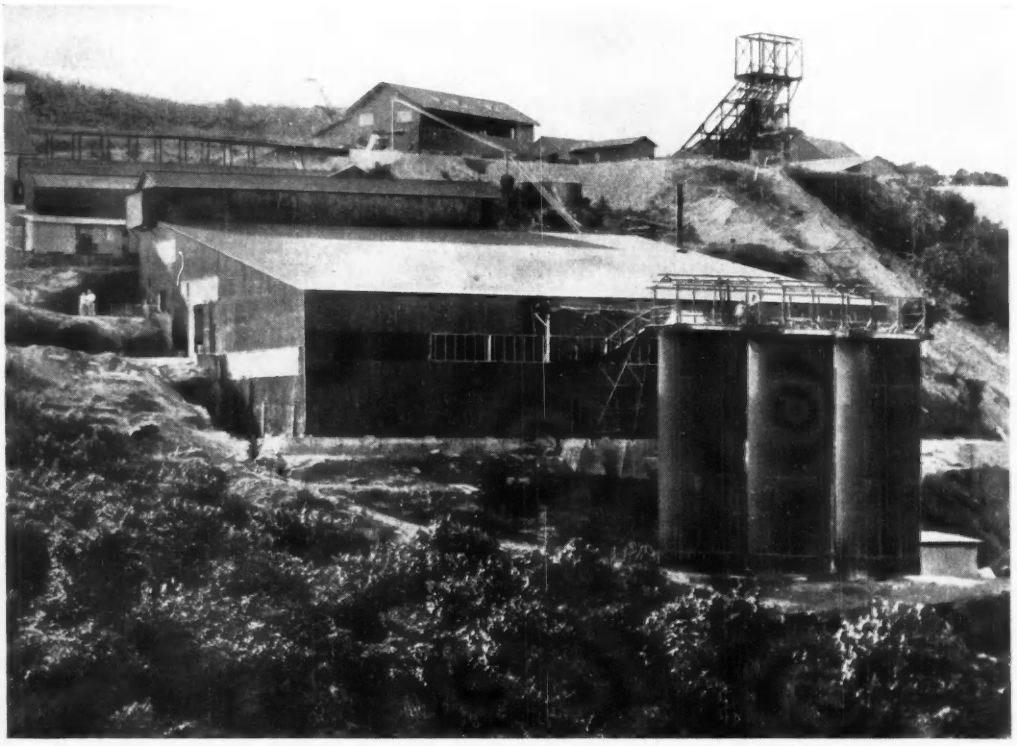
A very brief investigation was made to find what effect the colour of the light source had on the contrast. A plate was exposed behind a step wedge three times, the exposure (illumination x time) being the same in each case, but the light source was a tungsten filament lamp in the first case, a sodium

vapour lamp in the second, and a high pressure mercury vapour lamp in the third. The plate was then developed by the standard method, and the relation between exposure (on logarithmic scale) and density plotted for each type of light source. The results are shown in fig. 27. The source emitting light of longer wavelengths (sodium vapour) gives a slightly higher contrast than that emitting shorter wavelengths (mercury vapour), but the difference is quite small. The alteration in development time necessary to compensate for the effect could be obtained from fig. 7, but as the variation in contrast is within the limits of accuracy of the method of development, it is doubtful if much would be gained by making this correction.

The correction factors as obtained from fig. 7 are :—

Tungsten filament lamp x1.
Sodium vapour lamp x0.9.
Mercury vapour lamp x1.1.

Gold Mining Plant in West Africa.



170 ton Fraser & Chalmers cyanide plant installed for the Gold Coast Banket Areas Ltd., West Africa.

The Testing of Large Alternating Current Circuit Breakers

With Particular Reference to the New High Power Testing Laboratory at Witton.

PART I.—GENERAL OBSERVATIONS ON CIRCUIT BREAKER OPERATION AND TESTING.

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and

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Switchgear Dept., Witton Engineering Works.

In Part I. of this article, the authors discuss in a general manner the physical phenomena of circuit interruption and the way in which these phenomena affect the operation of circuit breakers. There will appear in subsequent issues of the G.E.C. Journal a complete description of the equipment and operation of the new High Power Testing Laboratory at Witton Engineering Works, and the results of tests made with the equipment.

1. INTRODUCTION.

THE object of testing any apparatus is to determine its fitness for the duty to which it will be subjected. In order, therefore, to devise suitable tests for circuit breakers, it is necessary to understand :—

(*a*) the physical principles underlying their operation,

(*b*) in what manner the features of the service to which they will be subjected affect the severity of their duty.

2. BREAKING CAPACITY OF CIRCUIT BREAKERS.

Fundamentally, the action of a circuit breaker may be said to be to interrupt a current *i* and, once the current is interrupted successfully, to resist its re-establishment by a voltage *e*. It would seem, therefore, that the breaking capacity of a circuit breaker should be rated in terms of *i* and *e*. All circuit breakers are in fact so rated, but there are certain differences between the various standard specifications as to the manner in which *i* and *e* should be defined for this purpose. The question of an international standard specification is being discussed by the International Electrotechnical Commission ; no agreement, however, has yet been reached.

At present in this country the method of rating is laid down by the "British Standard Specification for Oil Immersed Switches and Circuit Breakers for Alternating Current Circuits."*

*British Standard Specification No. 116—1929.

According to this specification, the breaking capacity of a circuit breaker is defined as "the *R.M.S.* current or kVA at a given rated voltage and frequency which it is capable of breaking under prescribed conditions."

The current broken or "breaking current" is defined as "the *R.M.S.* current at the instant of separation of the arcing contacts," and the *R.M.S.* current is to "be obtained from a mean square curve derived from a curve of squares obtained from the oscillogram." The kVA broken is to be calculated from the "recovery voltage" (that is the voltage that re-appears at the circuit breaker terminals after the extinction of the arc in all phases), and from the breaking current. It is also specified that tests to determine the breaking capacity of the circuit breaker shall be carried out at a power factor of 0.1 lagging. That is to say, it is primarily the current broken that is specified, but the current is subsequently multiplied by the recovery voltage to give a result which may be expressed in kVA. This is done in order to bring the ratings of circuit breakers into line with those of generators and transformers, although it should be remembered that the number of kVA thus obtained has not the same physical meaning as the kVA rating of, say, a machine. In the case of a circuit breaker it is merely the *R.M.S.* product of two instantaneous values.

3. THE BASIS FOR A RATIONAL TEST SPECIFICATION.

In order to be effective, a test specification must :—

(*a*) include all those factors which influence the performance of the apparatus in actual service,

(*b*) prescribe tests, the conditions of which are related logically to those in actual service, so that the performance of the apparatus in service can be predicted from the results of tests.

Condition (*b*) implies, among other things, a knowledge of the laws governing the performance of the apparatus, so that in case the conditions of service do not correspond exactly with those of the available tests, the service performance may be calculated.

At the present time, unfortunately, our knowledge of the theory of circuit breaker operation has not yet reached the stage where such calculations can be made with absolute certainty; further, although we know that the definition of breaking capacity embodied in B.S.S. No. 116 is imperfect and omits several important factors affecting the severity of the tests, it is extremely difficult to arrive at a concensus of opinion as to the way in which the definition should be modified. Before a final specification can be evolved, a considerable amount of research and discussion will be necessary.

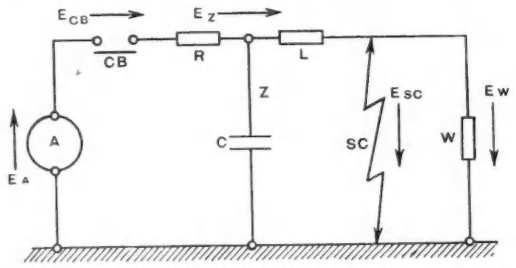

Fig. 1.—Elementary diagram of one phase of a system on short circuit.

A, alternator. CB, circuit breaker. W, load. SC, short circuit. Z, system impedance constituted by the elements resistance (R), inductance (L) and capacity (C).

4. CURRENTS AND VOLTAGES IN A SHORT CIRCUIT.

Consider a short circuit occurring in an elementary circuit as shown in fig. 1.

In this circuit a current I flows from the neutral through the alternator A, the circuit breaker CB, the line impedance Z (a complex quantity made up of the resistance R, inductance L and capacity C of the line) and then through the load W back to the neutral.

During normal service, the generator voltage E_A, which is assumed to be sinusoidal, is balanced by the load voltage E_W and the voltage drop E_Z in the line due to the current I (fig. 2). For the sake of simplicity, it is assumed that the alternator leakage reactance is included in the line impedance. E_{CB}, the voltage across the circuit breaker, is zero.

Suppose that at an instant α, a short circuit SC occurs near the load W.

The short circuit current which flows consists of two components; the first (i_s) is sinusoidal (if we neglect secondary effects, such as saturation of the iron) and its *R.M.S.* value is $\frac{E_A}{Z}$; the second (i_c) decreases exponentially from an initial value which is such that the result obtained by adding it algebraically to the instantaneous value of the sinusoidal component at the instant the short circuit begins, is equal to the instantaneous value of the load current which was flowing previously.

The *R.M.S.* value of the sinusoidal component is not constant, but decreases proportionally to the decrement of the alternator, which is in turn due to the demagnetising effect of the short circuit current upon the alternator field (armature reaction) causing the alternator terminal voltage to decrease exponentially towards a limiting value. The resultant short circuit current (I) is shown in fig. 2.

In general, Z is predominantly reactive, so that the short circuit current lags nearly 90° upon the alternator terminal voltage.

As the load is short circuited by SC the voltage across it disappears, and the entire *E.M.F.* of the alternator is utilised in driving I through the line impedance Z. E_Z is therefore equal and opposite to E_A.

After the lapse of a certain time, the circuit breaker contacts begin to part, and an arc forms between them. At this instant, β, a voltage drop appears across the circuit breaker terminals equal to the arc voltage, which is in phase with the current.

Each time the current I becomes zero there is now a momentary breakdown of the arc, due to its instability at low values of current, so that for a short period in each half cycle, the current remains zero. When this happens the *E.M.F.* of the generator builds up a voltage across the circuit breaker terminals (restriking voltage), which if the dielectric strength of the gap between the contacts is low enough, results in the restriking of the arc. The rate of increase of the restriking voltage is not infinite, but depends, as will be seen, upon the constants of the circuit. This alternate interruption and re-establishment of the current recurs a number of times, depending upon the characteristics of the circuit and the breaker, until sooner or later the dielectric strength of the gap is high enough to prevent the restriking of the arc altogether. When this happens (instant γ) the *E.M.F.* of the alternator appears as the "recovery voltage" across the circuit breaker.

The magnitude of the recovery voltage is increased under certain circumstances by a high frequency transient oscillation which is superimposed upon it and is caused by the dissipation of the energy

stored in the inductance and capacity of the circuit. This is shown in principle by fig. 2, from which it can be seen that subsequent to the instant γ, E_{CB} consists of two components ; first a supply frequency sinusoidal component, the maximum value of which increases exponentially corresponding to the building up of the alternator field after the removal of the demagnetizing effect of the short circuit current, and, second, a component of much higher frequency superimposed upon it, but which disappears rapidly, due to the damping introduced by the resistance of the circuit.

It should be noticed that in the interests of clarity the time scale of the phenomena shown in fig. 2 has been somewhat distorted. Thus the intervals between the incidence of the short circuit and the parting of the contacts and between the parting of the contacts and the final interruption of the current are usually longer than is shown in fig. 2. In addition the damping and frequency of the oscillation superimposed upon the recovery voltage are both usually greater than is indicated here, so that generally the oscillation disappears within the first half wave of the recovery voltage.

From this elementary discussion it will be seen that the circuit breaker does not itself interrupt the current. The current merely decreases to zero in the course of its cyclic variation, and is prevented by the circuit breaker from being re-established.

5. PHYSICAL PHENOMENA OF CIRCUIT INTERRUPTION.

As long as a current is carried by metallic conductors and the *E.M.F.* is maintained, it can only be interrupted by interposing in its path a gap constituted either by two contacts which are drawn apart (switch) or by destroying part of the metallic path (fuse). In each case the immediate result of introducing the gap is to cause an arc to be formed between the conductors on either side of it, so that quite generally the problem of circuit interruption becomes one of arc extinction, and all switches and circuit breakers, upon whatever principle they may be constructed, are devices for drawing an arc between contacts and then extinguishing it. The interruption of the circuit consists essentially in increasing the resistance of the space between the contacts from a value of the order of a fraction of an ohm to one of altogether greater magnitude. This being so, it is of importance to understand the phenomena which occur in the arc during its extinction.

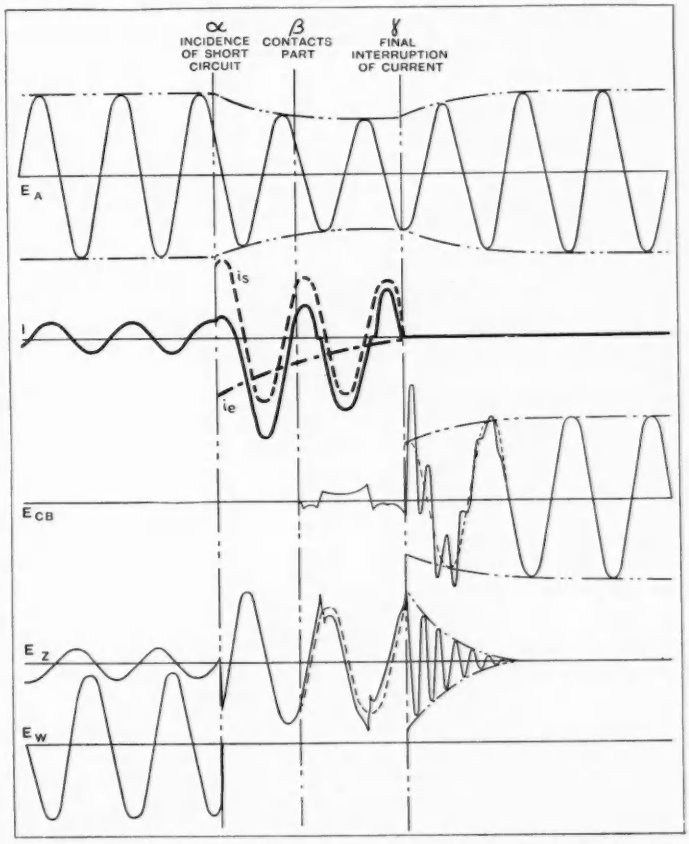

Fig. 2.—Currents and voltages in the system shown in fig. 1. The positive direction is indicated by the arrows in fig. 1 and positive quantities in the diagram are drawn above the zero axis.

CONDUCTIVITY OF THE ARC.

An arc is formed by the passage of a current through a gaseous medium, which may, as in the case of an oil circuit breaker, be produced by the arc itself through vaporization of the solid or liquid material surrounding it.

The atoms of all substances are thought to consist of heavy positively charged nuclei surrounded by a number of light negatively charged electrons, the total charge of which exactly neutralizes the positive charge of the nucleus. In order that a gas, such as that which surrounds the contacts of a circuit breaker when it opens under load, may become conducting it must be "ionized." That is to say, one or more of their satellite electrons must be split off from a proportion of the neutral atoms. This results in the formation of a certain number of negatively charged particles consisting of the liberated electrons, and a corresponding number of positive particles consisting of the nuclei of the atoms together with the remaining electrons.

Although a positive particle is several thousand times heavier than an electron, the electrostatic force acting upon it is usually the same as that acting upon the electron, or at most four or five times

greater, as the charge on the positive particle is either equal to that on the electron or at most a small multiple of it. The result is that the positive particles play the part, together with the undissociated atoms, of a more or less stable medium in which the electrons, moving under the influence of the potential gradient of the electric field, carry the current. The conductivity depends upon the number of free electrons present per unit volume and upon their mobility. It is found* that the conductivity of an arc column such as is formed between the contacts of a circuit breaker may be expressed as :

$$C_a = \frac{neb}{l} \cdot \frac{\pi d^2}{4}$$

where n = number of free electrons per cm^3.
b = factor expressing the average mobility of the electrons in centimetres per second per volt per centimetre.
d = diameter of the arc column.
l = length of the arc.
e = charge of the electron, *i.e.*, 1.59×10^{-19} Coulomb.

The value of C_a may be altered by varying any one of the factors n, b, d or l. The charge of the electron is of course a fundamental constant which does not alter.

The temperature and pressure in the arc column itself only vary to a limited extent, so that the variation of b, which depends upon these factors, is also small.

There remain, therefore, three possible ways of reducing C_a, namely,

(a) increase l.
(b) reduce d.
(c) reduce n.

To increase l sufficiently to produce extinction of the arc would, on a high tension system, mean drawing an arc many yards long, which is clearly impracticable. Attempts to reduce the diameter of the arc column at the inception of the arc, by drawing it through holes in baffles or pressing it between plates, have been unsuccessful, as the high temperature of the arc either destroys the material used for the baffles or renders it conducting. There remains, therefore, only the possibility of reducing n, that is of "de-ionizing" the arc column, or ensuring that the rate of removal of ions from the arc is greater than the rate at which they are formed.

FORMATION OF IONS.

The chief sources of ionization in a gas are :—

(a) thermal ionization, *i.e.*, ionization by collision of the atoms one with another, due to the agitation produced by high temperature.
(b) ionization by bombardment of the atoms by electrons which are accelerated to a high speed by the potential gradient of an electric field.
(c) photo-electric ionization due to the action of electro-magnetic radiation (light) upon the atoms.

In the arc, ionization of forms (a) and (b) is most important, and for the sake of brevity, they will be called T (thermal ionization) and B (ionization by bombardment).

DE-IONIZATION.

The charged particles may disappear from a region such as the arc column of a circuit breaker in two ways :—

(a) by recombination of positive and negative particles, in the arc column itself. This occurs under certain conditions when positive and negative particles collide.
(b) by diffusion of the mobile particles out of the region. One may suppose that the freely moving electrons which happen to move out of the core of the arc and arrive in the relatively cool outer layers, either reassociate with positive particles with which they come into contact, or adhere to neutral gas molecules, thus losing their mobility.

These processes may be called S (reassociation) and D (diffusion).

In the arc, therefore, there is a balance between T and B upon the one hand and S and D upon the other. If T and B preponderate, the ionization and conductivity will increase, if S and D preponderate, it will decrease. Of the four rates, T, B, S and D, it can be said to a certain degree of approximation that :—

T increases non-linearly with the temperature.
B increases linearly with the potential gradient, *i.e.*, with the applied voltage for constant separation of the contacts.
S increases approximately as the square of the number of free electrons per unit volume.
D is inversely proportional to the square of the diameter of the arc column.

These relations are only qualitative and serve merely to indicate the factors which have most influence upon the rate of appearance and disappearance of ions. There are many others which enter into an even approximate mathematical treatment of the question, but, owing to limitations of space, they cannot be dealt with here.

EXTINCTION OF D.C. ARCS.

In a D.C. arc between stationary contacts, a state of equilibrium in which $T + B = S + D$ is reached very soon after the arc is struck. In order to extinguish the arc, a condition must be produced in which $T + B < S + D$. The only practical means of doing this is to decrease $T + B$, as D and S

* See Kesselring and Koppelmann "Das Schaltproblem der Hochspannungstechnik." Archiv für Elektrotechnik, Vol. XXIX, January, 1935, page 12.

cannot be influenced to any great extent. This restriction, it should be observed, does not apply to the same extent to an A.C. arc, as will be seen later.

The only possible action is therefore to decrease the temperature of the arc column, by withdrawing energy from it *i.e.*, "cooling" it, to such an extent that $T + B$ decreases to a value less than $S + D$. It can, however, be shown that in most practical cases the first effect of withdrawing energy from the arc is to increase the amount of energy liberated. The arc current is determined by the *E.M.F.* of the generator and the resistance of the circuit, as this is in general large compared with that of the arc. The arc voltage is determined by the current, and is in general small compared with the generator *E.M.F.* If now the effective resistance of the arc is increased by "cooling," the current is not decreased very considerably, so that the arc voltage is increased and the energy liberated in the arc, which is the product of the current and the arc voltage, is augmented.

Thus

$$E - I.R. - E_{CB} = O \quad .. \quad .. \quad (1)$$

where E = *E.M.F.* of the generator,
I = current,
R = circuit resistance,
E_{CB} = arc voltage,

It follows from (1) that

$$I.E_{CB} = I.E - I^2.R, \quad .. \quad .. \quad .. \quad (2)$$

so that

$$\frac{d(I.E_{CB})}{dI} = E - 2.I.R. \quad .. \quad .. \quad .. \quad (3)$$

As E_{CB} is small compared with E, it is known from (1) that E is approximately equal to IR, from which it follows that E must be less than $2IR$, so that $\frac{d(I.E_{CB})}{dI}$ is negative, *i.e.*, as I decreases $I.E_{CB}$ increases. It can, however, be shown that there is a certain value above which $I.E_{CB}$ cannot increase, for, if R_{CB} is the arc resistance,

$$I = \frac{E}{R_{CB} + R}$$

$$\therefore \; I.E_{CB} = I^2 R_{CB} = \frac{E^2.R_{CB}}{(R_{CB} + R)^2}$$

The maximum value of this function occurs when $R_{CB} = R$, from which it follows that the maximum value of IE_{CB} is $\frac{E^2}{4R}$.

This expression, $\frac{E^2}{4R}$, represents the minimum rate of energy absorption that must be attained if the arc is to be extinguished, and is the rate which must be maintained until the energy stored as heat in the arc itself and as magnetic energy in the inductance of the circuit is so reduced that the arc collapses.

As an example, take a circuit fed by a 1,000 kW generator at 500 volts and having a loss in the transmission lines of 10 per cent. The current is $\frac{1{,}000{,}000}{500} = 2{,}000$ amperes, and the resistance of the lines is $\frac{100{,}000}{2{,}000^2} = \frac{1}{40}$ ohms.

The rate at which it is necessary to extract energy from the arc is therefore not less than

$$\frac{500^2}{4 \times \frac{1}{40}} = 2{,}500 \text{ kW.}$$

It will be seen that the power involved is large, but is nevertheless of an order that can be dealt with by apparatus of a practicable size.

EXTINCTION OF A.C. ARCS.

The condition for the extinction of an A.C. arc is the same as for that of a D.C. arc, *i.e.*, $S + D$ must become greater than $T + B$. The question is however complicated by the fact that the current varies continually in direction and magnitude, and in consequence the temperature and ionization in the arc column vary also at twice the supply frequency.

If for the moment the effect of the variation of the current is neglected and it is assumed that the thermal inertia of the arc is sufficient to maintain a constant temperature, the rate of extraction of energy required to extinguish the arc by pure cooling may be calculated in a manner similar to that used for D.C. arcs.

It can be shown that this is $\frac{E^2}{2X}$, where E is the alternator *E.M.F.* and X is the reactance of the circuit.

As an example, take a short circuit of 500,000 kVA occurring on a threephase network at 33 kV. The current per phase is $\frac{500{,}000{,}000}{\sqrt{3} \cdot 33{,}000} = 8{,}750A.$ and the reactance per phase therefore $\frac{33{,}000}{\sqrt{3} \times 8{,}750}$

$$= 2.18 \text{ ohms.}$$

It follows that energy must be extracted from the arc in each phase at the rate of $\frac{\left(\frac{33{,}000}{\sqrt{3}}\right)^2}{2 \times 2.18}$ watts, *i.e.*, 83,000 kW or, for all three phases together, at the rate of about 250,000 kW. It will be seen that if the extinction of such an arc depended only upon extracting more heat from it than could be supplied from the circuit, it would necessitate the absorption of very large quantities of energy indeed. The effect this would have on the design of circuit breakers can be seen if it is considered that the amount of gas

formed by the action of the arc upon the oil is about 50 cm^3/kW-second.* Suppose now, in the example above, that the arc is maintained for 3 half cycles, or 0.03 seconds at 50 cycles. The amount of energy dissipated is therefore:—

250,000 × 0.03 = 7,500 kW-seconds.

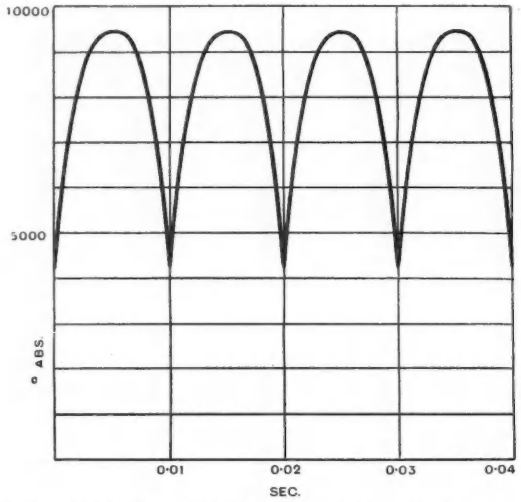

Fig. 3.—Variation of the temperature of a steady 50 cycle arc in air.

The volume of gas produced at normal temperature and pressure is therefore 7,500 × 50 = 375,000 cm^3 or 13.5 cu. ft. Even if in the first instant the high pressure and temperature at which the gas is produced counteract one another, expansion begins immediately, so that it may readily be seen that to withstand the resulting stresses, a very large circuit breaker indeed would be required.

Fortunately, the thermal inertia of an arc supplied at commercial frequencies is not so great that its temperature remains constant. Fig. 3† shows the results of measurements made at 50 cycles. These indicate that there is a cyclic variation between an upper and a lower limit at twice the supply frequency. The lower limit of the variation approaches zero at very low frequencies and rises towards the upper limit at high frequencies. It is, therefore, only for relatively high frequencies that it is true to say that arc extinction depends purely upon disturbance of thermal equilibrium.

On the other hand the variation of temperature does not follow the alternations of current so closely that complete extinction takes place at the passage of the current through zero. It is apparent from fig. 3 that even at frequencies as low as 50 cycles the thermal inertia of the arc may be great enough to maintain a certain degree of conductivity during the time when the current is reduced to a value (of the order of one ampere) at which the arc would become unstable and be extinguished if no such inertia existed.

It is clear that to base any theory of arc interruption on general considerations of energy balance is unlikely to be successful. It is therefore necessary to consider more in detail what happens in the arc column during the passage of the current through its zero value.

It has been explained that each time the current passes through zero there is an interval during which the current ceases altogether and the voltage across the gap builds up again to a value sufficient to restrike the arc and re-establish the current. The problem is, so to influence the vestiges of the arc column that its resistance increases at a greater rate than that at which the voltage across the gap can build up.

During the time the current is zero, there remains from the arc a column of hot gas of a certain diameter and degree of ionization, both of which, as the supply of energy has ceased, tend to decrease. On the other hand the voltage gradient along the gas column increases in proportion as the voltage between

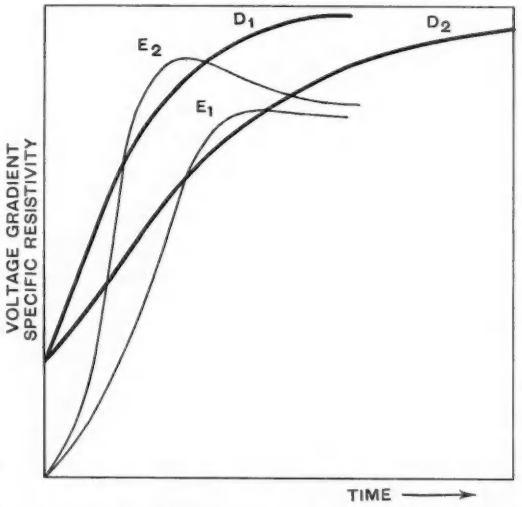

Fig. 4.—Relation between rate of increase of voltage gradient and rate of increase of dielectric strength in a circuit breaker.

the contacts increases, and tends to increase the ionization of the gas column both by collision and also by simple heating up.

The state of affairs is represented by fig. 4; if the voltage gradient across the gap (say curve E_1) is always less than the dielectric strength (curve D_1) the arc is not able to restrike and the current is broken.

If on the other hand either the rate of rise of the voltage gradient increases so rapidly (curve E_2) that it cuts the curve D_1 or the rate of increase of the

*See Rüdenberg, "Elektrische Schaltvorgänge," 3rd Edn. p. 275.

† Ornstein, Brinkmann and Vermeulen, Proc. Acad. Amsterdam 1931, No. 6, p. 764, quoted by Biermanns, E.T.Z. Vol. 53, 14.7.35, page 678.

dielectric strength (curve D_2) is decreased to such an extent that it cuts the curve E_1, the arc restrikes.

The process is thus a conflict between the tendency of the column of hot gas left behind by the arc to be de-ionized and the ionizing action of the restriking voltage, and in order to be able to predict the performance of a circuit breaker, it would be necessary to know exactly the conditions influencing both the ionizing and de-ionizing processes and the manner in which they vary. Unfortunately an exact mathematical treatment of the problem is impossible, due to the present limited knowledge of the phenomena, and would probably be extremely difficult were the phenomena fully explored. It is, however, possible to use existing knowledge to make estimates and discover trends which are extremely useful in the practical work of designing circuit breakers.

It can be shown that the result of the conflict between the ionizing and de-ionizing influences depends very much upon the diameter of the column of hot gas remaining from the arc. The pressure and nature of the gas are, of course, also of importance.

In fig. 5 are given the results of calculations made by Kesselring and Koppelmann,* which show the relation between the diameter of the arc column at the moment the current ceases and the voltage gradient necessary to restrike the arc. From these curves it is apparent that in the design of a circuit breaker, particular attention must be paid to methods of reducing the diameter of the arc column.

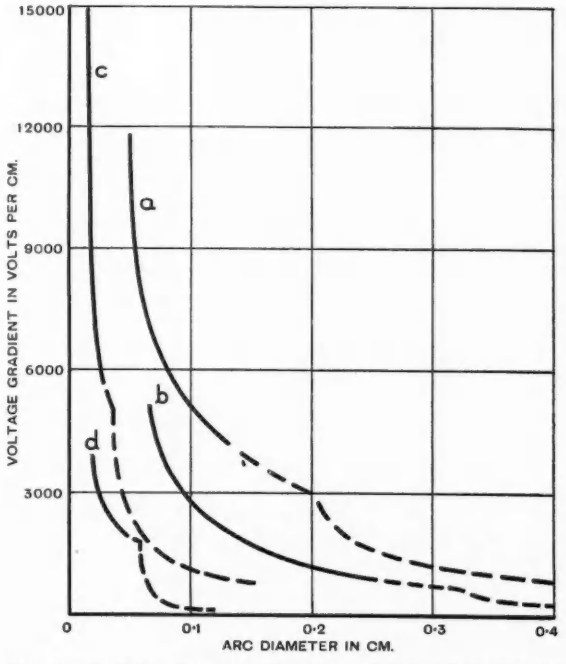

Fig. 5.—Relation between diameter of arc and restriking voltage gradient at the instant the current becomes zero.

Curve a. Hydrogen at 4 atmospheres abs. pressure.
,, b. ,, ,, 1 ,, ,, ,,
,, c. Nitrogen ,, 4 ,, ,, ,,
,, d. ,, ,, 1 ,, ,, ,,

* "Archiv für Elektrotechnik" Vol. XXIX, 1935, p. 28.

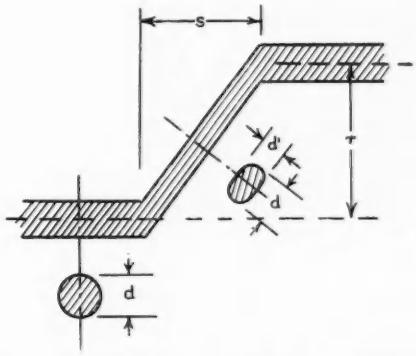

Fig. 6.—Influence of turbulence on the arc diameter.

Attempts to do this in the case of the active arc to which the supply of energy has not been cut off, either by stretching the arc or by compressing it between plates or in small holes, are not successful, as in the first place the arc voltage and in consequence the supply of energy adjust themselves automatically to the increased length, the diameter remaining practically constant, and in the other the passage is immediately enlarged by the arc attacking the material of which the baffles are made. Once the supply of energy to the arc is cut off, however, as is the case on the passage of the current through zero, it becomes more amenable, and by various methods, in particular that of inducing strong turbulence in the path of the arc or by blowing it out by means of a gas or oil blast, the length of the arc can be increased and its diameter reduced.

Thus consider a circular arc column of diameter d. Suppose now that over a length s a total displacement of r takes place (fig. 6) in consequence of turbulence of the medium in which the arc is immersed, so that the length of the section is no longer s but $\sqrt{s^2 + r^2}$.

The section of the column is changed to an ellipse, the minor axis of which is $d_1 = \dfrac{d.s}{\sqrt{s^2 + r^2}}$

For considerations of arc extinction this may be taken as being equivalent to a reduction of the diameter of the circular column to the value d_1.

Such a lateral movement of the arc column under the action of a blast is the effect observed in circuit breakers furnished with side-blast arc control devices.

It is found also that motion of the surrounding gas in the direction of the axis of the arc column produces an effect equivalent to the reduction of the

arc diameter, in that the column of hot gas is lifted a certain distance away from the surface of the contact. This is the effect produced in gas blast circuit breakers with axial blast.

6. FACTORS AFFECTING THE SEVERITY OF A SHORT CIRCUIT.

In the following paragraphs, the factors influencing the severity of a short circuit will be considered in detail, from the point of view of the circuit breaker which is called upon to interrupt it. These factors may be divided into two categories :—

(a) those affecting the current.

(b) those affecting the recovery voltage.

(a) Factors Affecting the Current.

(i) Configuration of the Network, Number, Capacity and Characteristics of the Alternators, Impedances of the Network Elements, and Position of the Short Circuit.

The calculation of the short circuit current that may be expected at a particular point on a network is frequently a matter of considerable difficulty, and it is not proposed to enter into a detailed description of the methods of calculation. It will suffice to mention that the magnitude of the current in a short circuit depends upon the number, capacity and reactance of the alternators feeding the network and the length and nature of the conductors between the short circuit and the generating plant. The presence of transformers in series with the lines diminishes the magnitude of the current, while synchronous motors or converters tend to increase it, because at the beginning of the short circuit they act as generators and feed back the kinetic energy of their rotating masses into the line. The calculation of the currents may also be complicated by the impedances of the phases not being equal.

Again the magnitude of the short circuit current is dependent upon the *E.M.F.* of the alternator, which is determined by the excitation. This again depends upon the load at the instant of short circuit and upon its power factor. The greater the load and the worse the power factor (if the current is lagging), the greater is the excitation, and the greater the short circuit current. An alternator supplying a capacitative load is under excited, so that the short circuit current is correspondingly reduced. It may even happen that with an exclusively capacitative load, the short circuit current is less than the load current.

(ii) Degree of Asymmetry.†

It is shown in text books* that when a source of alternating *E.M.F.* is suddenly applied to a circuit containing inductance and resistance, the resulting current is of the form:

$$i = I_{max}\left[\cos\left(2\pi ft + \phi\right) - \cos\psi\, \epsilon^{-\frac{R}{L}t}\right]$$

where $I_{max} = \dfrac{E_{max}}{\sqrt{R^2 + (2\pi fL)^2}}$ and ψ is the instant on the wave of *E.M.F.* at which the circuit is closed.

If it is assumed for the moment that the *E.M.F.* remains constant, *i.e.*, that the decrement of the alternator (see page 73) is neglected then the total

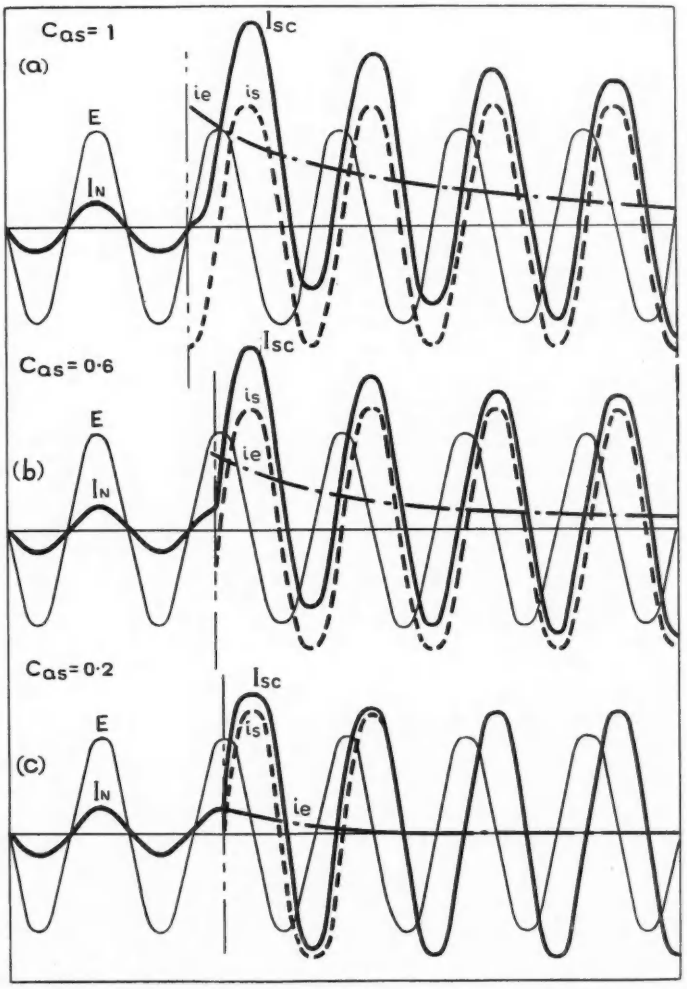

Fig. 7.—Variation of asymmetry with variation of instant of incidence of short circuit.

† It should be distinguished between asymmetry of the different phases of a circuit, and asymmetry in the sense which is discussed here, that is, as applied to a current which is not symmetrical about the zero axis.

* See, for instance, Rüdenberg, "Elektrische Schaltvorgänge" 3rd Edition, p. 8.

current that flows consists of two components :—

(a) a sinuosidal current (i_s) equal to that which would flow were the *E.M.F.*, *E*, applied to the impedance over a period of time, and the peak value of which is I_{max} as indicated above, and (b) a unidirectional (D.C.) component (i_e) the initial value of which may vary between *O* and *I*, according to the value of ψ at the instant of short circuit.

This is the so-called "doubling effect," and is shown in fig. 7 and also in fig. 2. In fig. 7 the applied *E.M.F.* in each case is *E*, and the normal load current I_N is in phase with *E*. The sinusoidal component (i_s) of the short circuit current I_{sc} is shown lagging 90° on *E*, as this is usually approximately the condition on short circuit. At (a) is the condition of maximum asymmetry where the short circuit occurs at zero voltage, and the degree of asymmetry, $C_{as} = \dfrac{\text{maximum value of } i_e}{\text{peak value of } i_s} = 1$. The initial value of i_e is equal to the peak value of i_s so that for several half waves, I_{sc} is nearly unidirectional.

At (b) a short circuit occurs about 75° later than at (a) and shortly before the voltage maximum. The degree of asymmetry is less than at (a), the maximum value of i_e at the instant of short circuit being 60 per cent. of the peak value of i_s.

At (c) the short circuit takes place at the voltage maximum and the component i_e is a minimum. At the instant the short circuit begins it is equal to the instantaneous value of the load current I_N ; in the figure $C_{as} = 0.2$.

Consider an asymmetrical current of the form :—

$$i = I\,(C_{as} + \sin\theta)$$

i.e., one consisting of a sinusoidal current $I \sin\theta$ superimposed upon a D.C. component $I.C_{as}$, where C_{as} is the degree of asymmetry.

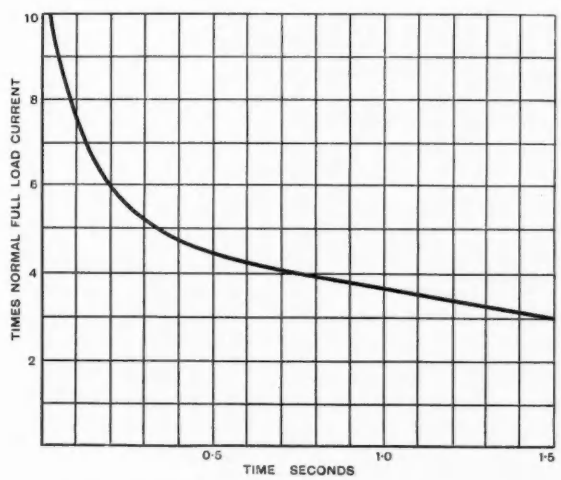

Fig. 8.—Decrement of alternator short circuit current.

The *R.M.S.* value of this current is

$$I_{RMS} = I \sqrt{\frac{\int_0^{2\pi} (C_{as} + \sin\theta)^2\, d\theta}{2\pi}}$$

$$= I \sqrt{C_{as}^{\,2} + {}^1/_2}$$

If $C_{as} = I$, $I_{RMS} = I\sqrt{\frac{3}{2}}$

If $C_{as} = O$, $I_{RMS} = I\sqrt{\frac{1}{2}}$

In the case of 100 per cent asymmetry, therefore, the *R.M.S.* value of the current is $\sqrt{3}$ times its value in the case of a symmetrical sinusoidal current.

The D.C. component increases the thermal and mechanical effects of the current upon the circuit breaker, which are proportional to the square of the *R.M.S.* value ; it may, however, as will be seen later, facilitate the actual interruption of the current.

(*iii*) *Decrement of the Alternators and Time Lag of the Protective Apparatus and of the Circuit Breaker.*

Hitherto only the initial value of the short circuit current has been considered. This is determined by the reactance of the system and the inherent, or leakage, reactance of the alternators. On a sustained short circuit, however, the large instantaneous value of the short circuit current is not maintained, but decreases rapidly to a value determined by the synchronous reactance of the machine.

This is, of course, due to the demagnetizing effect of the short circuit current upon the field. The rate at which the current decreases is proportional to its magnitude and is greater with laminated than with solid poles.

A typical curve showing the rate at which the short circuit current of an alternator decreases is given in fig. 8, which takes account not only of the decrement due to the demagnetization of the machine, but also to that due to the damping of the direct current component which gives rise to the asymmetry discussed above.

It is clear from this that the current which must be interrupted by the circuit breaker will vary according to the time which elapses between the inception of the short circuit and the parting of the contacts.

What value of the short circuit current should be used in calculations involving the rating of circuit breakers depends upon the rapidity of operation which is desired. A number of years ago, when it was not considered necessary for short circuits to be cleared very quickly, it was permissible to assume that the protective apparatus would have a time lag of 0.2 seconds or even more. It is found at the present time that much more rapid operation is necessary to preserve the stability of large systems, and that short circuits must frequently be interrupted within one or two cycles of their inception. This corresponds to a time lag of 0.02 to 0.04 seconds, so that the currents at the instant the

contacts part may approach 100 per cent. asymmetry, and the full instantaneous value.

The rapidity with which the circuit breaker itself functions has an important bearing upon the severity of its duty. The amount of energy liberated in the circuit breaker by the arc is equal to the product of the current and the arc voltage ; as the arc lengthens the arc voltage and therefore the energy liberated increases as shown by the curve *P* in fig. 9. This illustrates the rate of liberation of energy or "power" of the arc during the first few half cycles of the opening stroke.

By integrating the curve *P*, the curve *W* is obtained, which shows the increase of the total amount of energy liberated. Whether the rate of liberation of energy or the total energy liberated is the more important factor depends upon the type of breaker. For enclosed breakers such as oil circuit breakers, *W* is more important, as upon it depends the pressure developed. For gas blast breakers, *P* determines the rate at which energy must be dissipated by the blast. In either case it is obviously important that rapid operation is secured and also

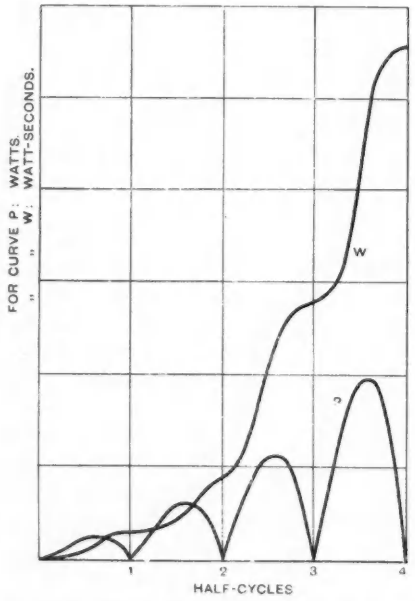

Fig. 9.—Liberation of energy in a circuit breaker.

that the arc is kept as short as possible consistent with its rapid extinction.

(b) Factors Affecting the Recovery Voltage.

In discussing the physical phenomena of arc extinction, it was seen that it is important to consider not only the maximum value to which the voltage across the circuit breaker rises after the extinction of the arc, but also the rate at which this voltage increases.

The current is interrupted by the circuit breaker at the instant at which it falls naturally to zero. As, however, under short circuit conditions the voltage almost invariably leads the current by nearly 90 degrees, the *E.M.F.* of the alternator has its maximum value at the instant the circuit is interrupted.

After the interruption of the current, this *E.M.F.* (which previously was balanced by the back *E.M.F.* induced by the changing current in the inductance of the circuit) builds up across the gap in the circuit constituted by the open contacts of the circuit

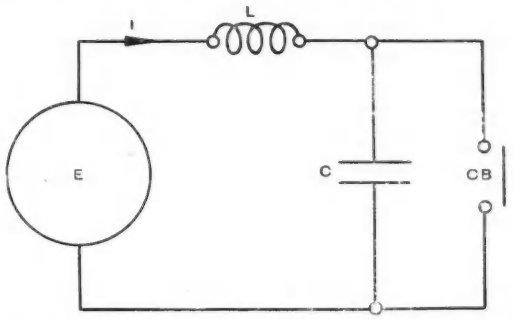

Fig. 10.—Elementary circuit for the illustration of recovery voltage.

breaker, and what is called the "recovery voltage" appears across the terminals of the breaker.

The rate at which the recovery voltage increases is of great importance, because upon the relation between it and the rate at which the dielectric strength of the gap is restored depends in great measure whether the current is finally interrupted or not.

In order to examine the factors upon which the rate of rise of the recovery voltage depends, an elementary circuit such as fig. 10 may be considered, consisting of an alternator *E* loaded by an inductance *L*, the current *I* passing through a circuit breaker *CB*. The capacity of the circuit is imagined to be concentrated in the condenser *C*, which is short circuited by *CB*.

It can be shown that if the circuit is suddenly opened at the instant the current is zero, the voltage that appears at the terminals of *CB* is of the form :

$$e = E\left(\cos 2\pi ft - \epsilon^{-at}\cos 2\pi f_1 t\right)$$

that is to say, it is the instantaneous value of the alternator *E.M.F.* ($E \cos 2\pi ft$, where f is the supply frequency) with a transient oscillation of frequency f_1 superimposed upon it.

The rate of increase of the voltage immediately after the cessation of the current is thus dependent primarily upon the instantaneous value of the alternator *E.M.F.* at that instant and upon the amplitude and frequency of the transient oscillation.

The influence of various characteristics of the short circuit and of the circuit breaker upon these two quantities will next be examined.

(*i*) *Power Factor of the Circuit.*

In a circuit containing neither inductance nor capacity the voltage across the circuit breaker would assume the instantaneous value of the generator *E.M.F.* immediately the circuit was interrupted. The presence of inductance and capacity prevents this instantaneous adjustment of the voltage, and compels it to change its value more or less gradually. Nevertheless the instantaneous voltage of the alternator at the moment of current interruption has a deciding effect upon the rate at which the voltage increases. If the instantaneous voltage is high, the rate of rise is great and *vice versa.*

As in commercial circuit breakers the extinction of the arc always takes place at a current zero, the power factor of the circuit has a great influence upon this point.

If the power factor is unity, and the current in phase with the voltage, the generator voltage is zero at the instant of current interruption, so that the rate of rise of recovery voltage is small (fig. 11a).

On the contrary, in a strongly inductive or capacitative circuit the voltage is at a maximum at the instant the current is interrupted, and the rate of rise of recovery voltage is correspondingly large. (Fig. 11, b and c.)

It is possible for very high voltage surges to occur when the current in a purely capacitative circuit is broken, as for instance when an unloaded cable feeder is switched off. These may be caused by the arc re-striking across the contact breaker contacts after having been interrupted; such a breakdown is followed by a very short and sudden current surge which charges the capacity to a voltage equal to the instantaneous value of the *E.M.F.* at the instant of breakdown. This current falls very rapidly so that the arc extinguishes almost immediately, leaving the capacity charged up so that the voltage across the circuit breaker is equal to the difference between that across the capacity and the alternator *E.M.F.* As soon as this voltage is again high enough to break down the gap insulation, a further current impulse flows leading to a further charging up of the capacity.

Under certain circumstances, the voltage across the circuit breaker may increase to twice the peak voltage of the alternator *E.M.F.* or more.

In practice, however, such voltage rises are of infrequent occurrence. They depend upon the arc restriking a number of times after the resistance of the arc column has risen to such a value that the charge in the capacity cannot leak away in the intervals between the successive breakdowns of the gap. This is a state of affairs which should not arise with a well designed breaker.

The power factor of most short circuits is very low (usually not much more than 0.3) and the current lags upon the voltage, giving rise to the conditions shown in fig. 11b. The conditions for circuit interruption are therefore severe, and this is why it is specified that when testing the breaking capacity of circuit breakers, the power factor of the circuit shall be low, generally lower than 0.3.

(*ii*) *Degree of Asymmetry.*

It is shown in fig. 7 that, during the first few cycles of a short circuit, the current may be more or less unidirectional. This has the effect of displacing the instants at which the current passes through zero. In the case of a low power factor circuit the displacement of the current zero facilitates the final extinction of the arc by reducing the value of the recovery voltage. The current zero (fig. 12a), instead of happening at an instant when the alternator *E.M.F.* is at a maximum, occurs later, by which time the *E.M.F.* is itself decreasing towards zero. In addition to this, the fact that the current

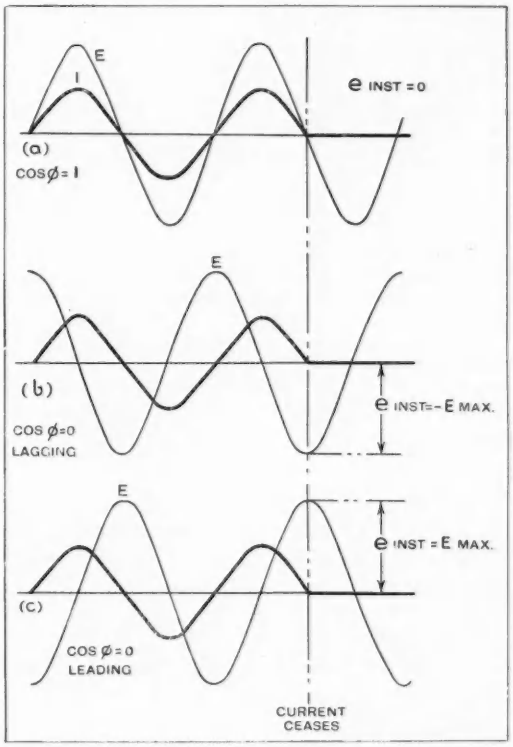

Fig. 11.—Effect of power factor of the circuit on the rate of increase of the recovery voltage.

wave is displaced causes two current zeros to follow at an interval of less than one half cycle, so that should the arc restrike after the first passage through zero, there is less chance of this recurring after the second one, as the intensity of current in the interval is low.

If on the other hand the circuit has a relatively high power factor (fig. 12b) the opposite effect is produced, as the D.C. component not only increases the *R.M.S.* value of the short circuit current and thus the duty of the breaker, but displaces the

current zero to an instant when the alternator *E.M.F.* is higher than would be the case were the short circuit current symmetrical.

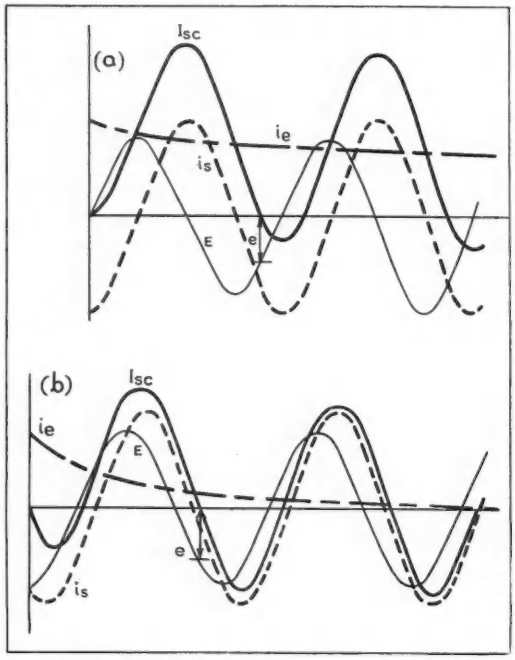

Fig. 12.—Effect of D.C. component of short circuit current upon the recovery voltage.

(iii) Decrement of Alternators.

It is clear that the decrement of the alternators (discussed on page 73), which results in a progressive reduction of the short circuit current during the initial period of a short circuit, must also reduce the magnitude of the recovery voltage.

The demagnetizing effect of the armature reaction, which requires a finite time to appear, requires also a finite time to disappear, so that immediately after the interruption of the short circuit current, the generator *E.M.F.* increases progressively, towards an asymptote constituted by the normal no load value corresponding to the actual excitation.

The reduction of the alternator *E.M.F.* depends upon the magnitude of the short-circuit current, so that it is less during a short-circuit which occurs at a point on the system remote from the alternator than during one which occurs in its immediate vicinity. It follows that although the current to be broken by the circuit breaker is less in the former case the recovery voltage is greater.

The system of "super-excitation" of the testing alternator used in the G.E.C. High Power Testing Laboratory greatly increases the severity of the short circuit by counteracting the reduction of the generator *E.M.F.* by the armature reaction. On the one hand this reduces the decrement of the short circuit current and on the other results in a higher recovery voltage.

(iv) Type of Fault on the Network.

Under certain conditions of short circuit, the supply frequency component of the recovery voltage may exceed the service voltage of the circuit by a considerable amount.

For instance, in fig. 13a, if an earth occurs simultaneously on the conductors *A* and *C'*, the points *A*, *A'*, *B'* and *C'* assume approximately the same potential, as *A* and *C'* are earthed and the potential of *A'* and *B'* only differs from that of *A* and *C'* by the normal voltage drop in the conductors. The recovery voltage on phase *A* is therefore zero, while it is $\sqrt{3}$ times the phase voltage *E* on the other two phases.

Fig. 13b shows the effect of synchronizing two systems at 180 degrees displacement. The recovery voltage on each phase is $2E$.

An unlikely but nevertheless possible occurrence is shown in fig. 13c, where two systems are synchronized at 180° displacement at an instant when both are earthed in the same phase. The recovery voltage in the two unearthed phases is then $2\sqrt{3}\ E$.

It should be noticed that in case (*a*) although the recovery voltage on phases *B* and *C* is increased, the current in these phases is small, as

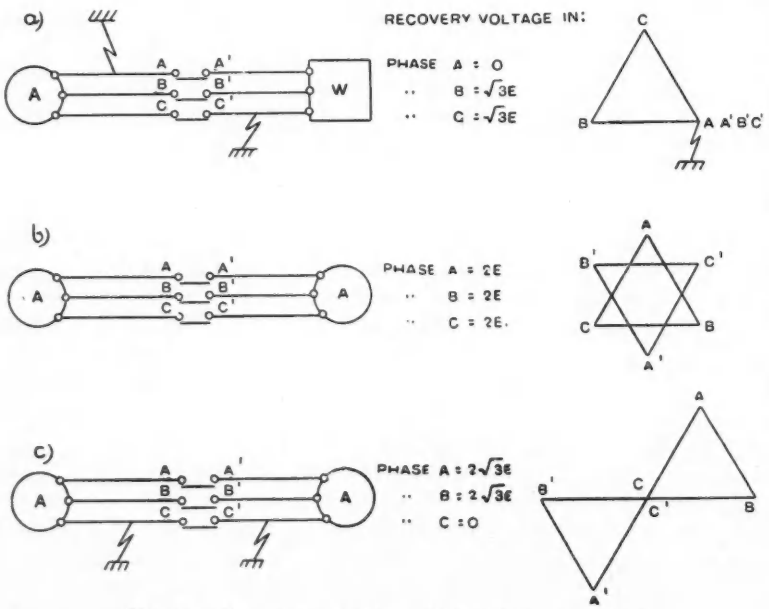

Fig. 13.—Recovery voltage on different forms of fault.
E = System phase voltage. A = Alternator. W = Load.

it is limited by the load impedance, while in phase *A* of the breaker there is no current at all as it is short circuited by the fault.

Also, in cases (*b*) and (*c*) the maximum current that can flow is limited to the short circuit current of the smaller of the two alternators concerned, so that although the recovery voltages are high, the short circuit currents are moderate.

(*v*) *Effect of Number of System Phases.*

Hitherto, the short circuits in one phase of a polyphase system have been considered, without mention having been made of the effect of the phenomena in any one phase upon those in another. The great majority of circuit breakers, however, are used on three-phase systems and are tested on three-phase short circuits.

At the beginning of a three phase short circuit all three phases have equal currents (assuming the short circuit is phase-symmetrical) I_{SC1}, I_{SC2}, I_{SC3} in fig. 14. Owing to unavoidable differences between the three phases of the circuit breaker, the arc in one phase is bound to extinguish before those in the other two, so that only two instead of three phases are short circuited (fig. 15). Suppose phase 1 extinguishes first. Referring to fig. 15, it is seen that the neutral point of the voltage vectors is displaced from *O* to *O'*, so that the phase voltage on the phases which are still short circuited falls to $\frac{\sqrt{3}}{2}$ *Ep* (where *Ep* is the original phase voltage) and are advanced and retarded 30° respectively. The currents are correspondingly reduced and fall to zero at the same moment 90° after the current in phase 1 ceases (fig. 14). The important thing to notice, however, is that the recovery voltage in phase 1, although it does not alter its phase angle is increased from *Ep* to 1.5 *Ep*.

The first phase to break in a three-phase breaker, therefore, breaks the phase short circuit current with 1.5 times the phase recovery voltage, while the other two phases break $\frac{\sqrt{3}}{2}$ times the phase short circuit current, with the phase recovery voltage.

On this account it is necessary, should only one phase of a three-phase breaker be tested, to conduct the test at a voltage 50 per cent higher than the normal voltage in order that the results so obtained may be comparable with those of a three-phase test.

(*vi*) *Natural Frequency of the Network.*

Referring again to page 74 and to fig. 16, the effect of the transient component of the voltage which reappears across *CB* in fig. 10 when it is opened suddenly will now be considered more particularly. It follows from what has been stated on page 74, that the frequency of the transient is given by: $f_1 = \frac{1}{2\pi\sqrt{LC}}$, which is the "natural frequency" of the circuit.

In practice the transient is damped (*i.e.*, it

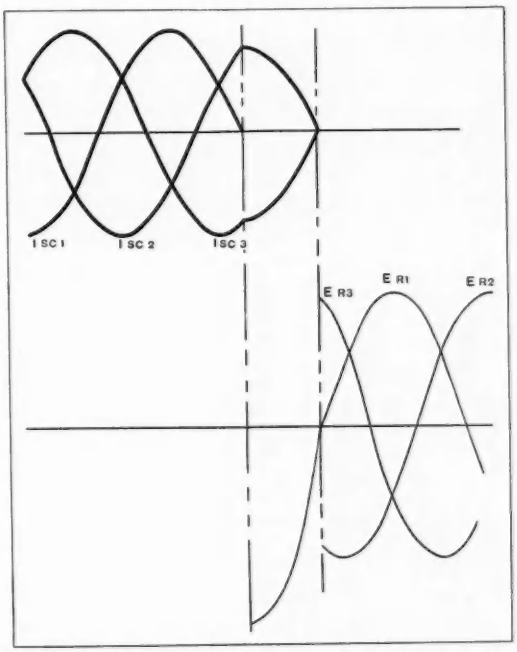

Fig. 14.—Short circuit currents and recovery voltages on a three phase short circuit.

disappears more or less rapidly) because there is always a certain amount of resistance in the circuit; at the moment, however, as only the first half wave of the transient is being discussed, this damping may be neglected.

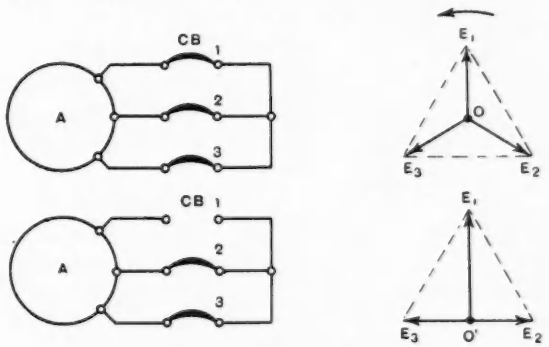

Fig. 15.—Displacement of neutral on interruption of one phase of a three phase short circuit.

If the voltage across *CB* at the instant the current is interrupted is zero, then immediately after the contacts part, *e* must be zero, so that $E \cos 2\pi ft$ must be equal to $E \cos 2\pi f_1 t$. That is, the amplitude of the transient oscillation is equal and opposite to the maximum value of the generator *E.M.F.E.* This is shown in fig. 16, in which *I* is the current which is interrupted by *CB* at the time *O*. Subse-

quent to *O*, there persists a small high frequency current in the capacity *C* (fig. 10), which dies away at the same rate as the voltage transient. After a time $\tau = \frac{1}{2f_1} = \pi\sqrt{LC}$ seconds, the transient component attains its positive maximum value, so that the total voltage across *CB* is twice the maximum value of the alternator *E.M.F.* as shown by fig. 16b.

This holds true if it be assumed that the voltage across *CB* is zero at the moment the arc is extinguished. In the case of a circuit breaker this is not strictly true, because before the circuit is finally broken there is always an arc between the contacts.

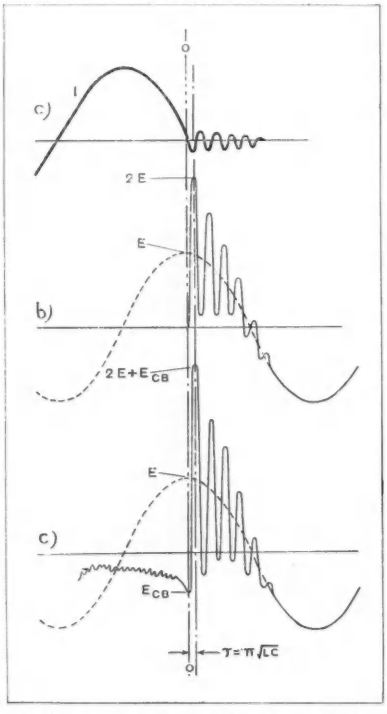

Fig. 16.—Influence of arc voltage on recovery voltage.

The resistance of the arc varies inversely as the current, so that as the current falls towards zero, the arc voltage (E_{CB}) increases as is shown in fig. 16c. It is obvious that as *I* approaches zero, and E_{CB} therefore tends to become very large, a certain diversion of the current into the capacity *C* takes place, so that the wave form of E_{CB} changes more or less gradually from the jagged shape characteristic of the arc to a sinusoidal form determined by the capacity. The result is that at time *O* there is a certain voltage E_{CB} across *CB*, so that the initial amplitude of the transient is no longer *E*, but $E + E_{CB}$, and after a lapse of $\pi\sqrt{LC}$ seconds, the voltage across *CB* is approximately $(2E + E_{CB})$.

It follows from the above that the average rate of rise of the voltage across *CB* is $\delta = \frac{2E + E_{CB}}{\pi\sqrt{LC}}$ volts per second; this quantity is one of the most important factors affecting the severity of the duty of a circuit breaker when interrupting a short circuit.

The magnitude of δ depends, as has been seen, upon the value of *E* at the instant of current interruption, which in turn depends upon the decrement of the alternator, the power factor, etc., as explained above; δ, however, is much less dependent upon such factors than upon the value of f_1, which is itself determined by the values of the inductance and capacity of the circuit. It is found that f_1 may vary between 100,000 periods per second in a high power test plant, the machines and apparatus in which are specially designed to have a low inductance and capacity and 500 periods per second in a supply network fed by alternators with large reactance through highly capacitative cables.

Other things being equal, therefore, the duty of a circuit breaker is much more severe in a test plant of high natural frequency than on a network the natural frequency of which is comparatively low, because the average rate of rise of the recovery voltage is very much greater in the first case.

In practice, the arrangement of the inductances and capacities is seldom so simple as is shown in fig. 10. Circuits are usually composed of a number of different inductances and capacities, either concentrated or distributed, and connected either in series or parallel. Thus, instead of only one natural frequency there may be a series of frequencies superimposed one upon the other, resulting in a more or less irregular wave shape, in which it is difficult to detect any harmonic components at all. Added to this, the phenomena of current interruption may not be so simple as described above. It may happen that the current does not cease once and for all on its passage through zero, but may cease and be re-established several times during the interval in which the recovery voltage is rising to its maximum value. As this time is very short (in an average high power test plant it may be of the order of 0.5×10^{-4} sec.) it is a matter of considerable difficulty to investigate what actually happens. A certain number of measurements have, however, been made, which seem to show that the phenomena are more complicated than is generally supposed. Fig. 17 for instance shows an oscillogram given by von Borries and Kaufmann,* in which the current passes through zero three times before being finally interrupted. At the first passage there is one voltage peak of 31 kV, at the second two peaks of 54 kV and 30 kV respectively, at the third one of 50 kV and another of 41 kV, and it is not till the end of the third half wave that the current is finally interrupted and the recovery voltage transient takes on a sinusoidal form. At present there is little exact information available upon the mechanism of the recovery voltage, nor is its

* Zeitschrift des VDI., 18/5/35, p. 597.

influence upon the severity of circuit breaker duty accurately known. All that can be said is that in general the higher the rate of recovery the more severe is the duty, and a fruitful field of research lies open to organizations with the necessary equipment to investigate these questions.

(*vi*) *Type of Circuit Breaker.*

It has been shown in the previous section that the value of the peak of the arc voltage just before the passage of the current through zero has a considerable effect upon the recovery voltage rise after the current ceases. The value of the voltage peak depends to some extent upon the constants of the circuit, but more upon the characteristics of the circuit breaker itself.

Thus with a plain break oil circuit breaker, in which the arc develops comparatively free of restraint, the peak of arc voltage is small. In a gas blast breaker of high capacity with a high pressure blast, and especially on interrupting a short circuit of limited power, the peak may be high.

It might therefore be suspected from a superficial consideration, that the application of a very powerful blast, in order to secure rapid extinction of the arc, would defeat its own object by causing an excessive rise of voltage at the terminals of the breaker immediately after the first interruption of the current, which might cause a renewed breakdown.

This is, however, not the case, as the following consideration shows; the reason why the voltage peak is high immediately before the interruption of the current is because the resistance of the arc path is high, that is, because its degree of ionization is low. The conditions are therefore correspondingly more favourable for the final extinction of the arc by further reduction of the ionization of the arc column after the cessation of the current.

Another characteristic of the circuit breaker that influences the rate of rise of the voltage is what is known as "post-arc conductivity." The resistance of the arc column does not rise to infinity immediately after the interruption of the current, but remains at a certain finite value. The arc column has therefore a certain conductivity which is shunted across the oscillatory circuit formed by the inductance and capacity of the circuit. Its effect is to increase the damping and decrease the frequency of the high frequency oscillation that accompanies the building up of the voltage across the breaker and thus to decrease the average rate of rise of the voltage. In this way a high post-arc conductivity facilitates the interruption of the current.

It must not be forgotten, however, that the effect of the persistence of the current is to help to maintain the temperature of the arc column, and thus to encourage thermal ionization. This may be so considerable as to balance or even outweigh the advantage gained by the reduction of the rate of rise of the voltage.

It is frequently suggested that when a test certificate for a circuit breaker is being issued, the rate of rise of the voltage across its terminals after interruption of the current should be quoted as an indication of the severity of the test to which the breaker had been subjected. The above considerations show that such information would be useless and might even be misleading, as the rate of rise depends not only upon the test plant but also upon the breaker itself. Thus it would be quite possible to have a very good breaker, the characteristics of which were such as to give a low rate of rise of voltage. If such a breaker were tested, and the rate of rise of voltage were quoted, it would always appear that it had been subjected to a milder form of test than a breaker of similar breaking capacity but whose characteristics were such as to give a high rate of rise of voltage, even though both were tested under precisely the same conditions. From these remarks it must not be supposed that it would not be useful to include the natural frequency of the test circuit in the test report. This figure would give a valuable indication of the severity of the test. The point is that the true natural frequency cannot be measured from the oscillographic records of the test of the breaker upon which the report is being made.

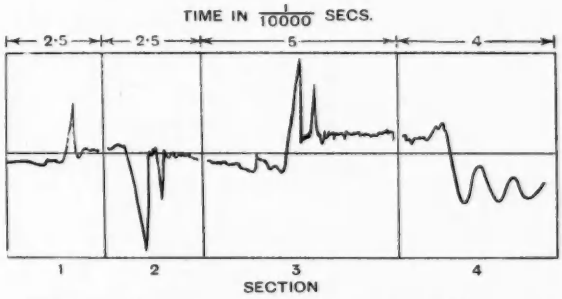

Fig. 17.—Cathode ray oscillogram of restriking and recovery voltages on the passage of the short circuit current through zero, (sections 1, 2 and 3) and on the current being interrupted (section 4). The oscillogram is not continuous, as sections between those shown have been omitted to reduce the total length.

7. GENERAL PRINCIPLES OF CIRCUIT BREAKER DESIGN.

As a conclusion to the above remarks, it may be interesting to summarize shortly their bearing upon the design of circuit breakers.

The guiding principle is that an alternating current circuit breaker is a device for drawing an arc between two contacts and then suppressing it. The circuit breaker must be so constructed that the arc is drawn with the optimum rapidity and then extinguished as soon as possible. The breaker must

withstand the thermal effects of the arcing and be sufficiently strong mechanically to withstand the electromagnetic stress due to the heavy currents and the mechanical stress due to rise of pressure inside the envelope. The dielectric strength of the insulators must be sufficient to withstand the applied voltage even under the unfavourable conditions of high temperature and mechanical stressing produced by arcing and heavy currents.

Finally, the breaker must be constructed in such a manner that by taking advantage of the momentary pause which occurs at the end of each half cycle of the alternating current, it can raise the dielectric strength of the gap between the parted contacts to a value sufficient to withstand the voltage caused by the alternator *E.M.F.*

In order to do this effectively, it is necessary to surround the contacts and the arc by some non-conducting medium which is capable of cooling and de-ionizing the hot gas contained in the arc column.

The specific heat and thermal conductivity of the medium should be as high as possible. In this respect it is interesting to observe that the success of the oil circuit breaker probably depends to a great extent upon the fact that the gas which is formed by the dissociation of the oil is mostly hydrogen, which has a high thermal conductivity and specific heat. Reference to fig. 5 shows a further reason why the presence of hydrogen is favourable to arc extinction.

The action of the surrounding medium is more effective if it is very turbulent or is given a rapid motion either parallel or at right angles to the arc column.

8. CHARACTERISTICS OF A CIRCUIT BREAKER TESTING PLANT.

As the voltage and currents met with in power networks have increased, the difficulty and expense of supplying adequate test facilities for the apparatus employed has increased proportionately.

The High Tension Laboratory (G.E.C. Journal, Vol. 1, No. 4, p. 161) and the existing test facilities in the High Tension Works at Witton allowed all routine tests and development work on the largest circuit breakers, transformers and H.T. apparatus to be carried out with the exception of high power breaking capacity tests upon circuit breakers. The test equipment has now been completed by the installation of the High Power Testing Laboratory.

The largest standard breaking capacity rating specified by the British Standards Institution (B.S.S. 116) is 1,500,000 kVA. This corresponds to a breaking current of $\frac{1{,}500{,}000}{\sqrt{3}\ 11} = 79$ kA at 11 kV, which is the lowest voltage for which this breaking capacity is ever likely to be necessary.

The breaking current corresponding to 1,500,000 kVA at 132 kV, which is the highest voltage used in this country, is 6.6 kA.

79 kA at 11 kV and 6.6 kA at 132 kV represent, therefore, the limits of output which are likely to be required, and the Witton High Power Testing Laboratory has been designed to cover this range. In order to have a certain margin, however, the maximum available capacity is of the order of 2 million kVA.

The power is supplied by an alternator, driven by a motor which is disconnected from the supply during the short circuit, and the kinetic energy of the rotating masses supplies the necessary power. It is possible by special measures to reduce the instantaneous reactance of a large alternator to about $2\frac{1}{2} - 3$ per cent, so that the instantaneous short circuit current is approximately 40 times the normal full load current. For a short circuit capacity of 2 million kVA, therefore, a machine normally rated at 50,000 kVA is necessary.

As it is desirable to maintain the high value of the short circuit current for a period of several cycles, some means of overcoming the decrement due to the armature reaction is necessary. This can be provided by boosting the excitation to four or five times normal value during the short circuit. For this a very large exciter is of course necessary.

To obtain the maximum short circuit current, the highest natural frequency and lowest power factor, the inductance, capacity and resistance of all parts of the installation must be reduced to the lowest values possible.

This can be done by making all connections as short and the installation as compact as possible, running connections in air and at minimum spacings, using low reactance transformers and so on. To avoid the use of transformers as much as possible, a high voltage alternator (say 20 kV) is desirable.

In addition to the generating plant, very extensive measuring apparatus is necessary. As has been shown, many short circuit phenomena can be followed by means of the electro-magnetic oscillograph. Others, such as the wave form of the restriking and the recovery voltages, make a cathode ray oscillograph necessary if the finest details are to be recognized.

(*To be continued*).